BASIC MECHANICAL ENGINEERING

Contents

UNIT 1

MATERIALS

CLASSIFICATION OF ENGINEERING MATERIALS

Q.1. What are engineering materials ?

Ans. Engineering materials are the stuff, of which something is made. In every sphere of human activity, engineering materials are used in one form or the other. They constitute the backbone of the modern civilization. Engineering materials comprises a wide range of metals and non-metals, which can be operated upon to form an end product.

All materials available cannot be considered as engineering materials. An engineering material should possesss following characteristics –

(i) It should be able to get shaped (e.g., cast, forged, formed, machined, sintered etc.) and joined easily with other materials (e.g., welded, brazed, etc.).

(ii) It should have adequate dimensional stability, corrosion resistance, strength, toughness, hardness, heat resistance, low electrical resistance, high fatigue resistance, etc.

(iii) Material selected should provide goods at lower cost to procure higher profit with all required qualities present in it.

Q.2. Give a brief classification of engineering materials.

(R.G.P.V., Dec. 2016)

Or

Give the broad classification of engineering materials.

(R.G.P.V., Dec. 2012)

Ans. The engineering materials may be broadly classified into following three categories –

(i) Metals (ii) Non-metals

(iii) Materials due to combination.

(i) Metals – Metals are elemental substances capable of changing their shape permanently. They are composed of elements which readily give

up electrons to provide a metallic bond and electrical conductivity. Metals may be ferrous or non-ferrous type. The ferrous metals contain Fe and C as their constituents. The behaviour and properties of ferrous metals depend upon the percentage and the form of carbon present in them. They are iron and steel.

Non-ferrous metals do not contain Fe and C as their constituents. Examples of commonly used non-ferrous metals are Al, Cu, Ag, Zn, Ni, Sn, Cr, Pb etc. Al, Cu, Ag and Au are good conductors of electricity. Ag is most malleable, Au is most ductile and Cr is corrosion resistant. Zn is used in the metal plating, Sn is used to make bushes, and Ni imparts strength and creep resistance.

(ii) Non-metals – They can be further classified as ceramics and organic polymers.

Ceramics are generally metallic or non-metallic oxides. Physically separable and chemically homogeneous constituents of materials consisting of phases are also called ceramics. Rocks, glasses, fireclay and firebricks, cements and limes are some commonly used ceramics. Ferrites, garnets, ferro-electrics and ceramic superconductors are the latest development in this area.

Organic polymers are derived mainly from the hydrocarbons. These consist of covalent bonds formed by carbon, chemically combined with oxygen and hydrogen. The polymers are obtained from monomers bonded by a chemical reaction (a process called polymerization). In this process, long molecular chain having high molecular weight is generated. Organic polymers are relatively inert and light, and generally have a high degree of plasticity. Bakelite, polyethylene, nylon, teflon are some examples.

(iii) Materials Due to Combination – They may be alloys or composites.

An alloy is a combination of two or more metals. They possess properties which are quite different from those of their constituent metals. Alloys may be errous or non-ferrous depending on the base metal used. An alloy is prepared or a specific purpose to meet the particular requirements of an application. ome common ferrous alloys are Invar, stainless steel and high speed steel (HSS). on-ferrous alloys include phosphor bronze, brass, duralumin, babbits, etc.

Composites may be inorganic or organic. They have two or more nstituents of dissimilar properties. The two major constituents may be metals d ceramics, or metals and polymers, or ceramics and polymers or any other mbination. Instead of metals, alloys may also be used to make composites. e of the constituent of composites called reinforcing constituent may be in ticulate form, fibrous form or flake form.

Q.3. Compare properties of ferrous and non-ferrous metals. ***(R.G.P.V., Dec. 2015)***

Ans. All the metals used in engineering work can be classified as ferrous non-ferrous metals.

Metals in which chief constituent is iron (Fe) are called ferrous metals. Along with iron these also consist carbon, manganese, phosphorus, sulphur etc. These are very important engineering construction materials.

Metals which do not contain iron are called non-ferrous metals. These include metals like copper, aluminium, lead, tin, magnesium and zirconium etc., and their alloys.

A comparison of properties of ferrous and non-ferrous metals is given below.

S.No.	*Ferrous Metals*	*Non-ferrous Metals*
(i)	Higher melting point	Lower melting point
(ii)	Higher density	Relatively low density
(iii)	Relatively heavy	Light in weight
(iv)	Higher strength	Lower strength
(v)	Shrinkage is less	Shrinkage is generally more
(vi)	Cold working is difficult	Cold working is easy
(vii)	Less soft	Softness is more
(viii)	Susceptible to corrosion	High resistance to corrosion
(ix)	Highly magnetic due to iron content	Anti-magnetic
(x)	Economical to use.	More costly.

COMPOSITION OF CAST IRON AND CARBON STEELS

Q.4. What is cast iron ? ***(R.G.P.V., Dec. 2016)***

Ans. The cast iron is obtained by melting pig iron with coke and limestone in a furnace. It is an alloy of iron and carbon. It contains about 2 to 4% of carbon. It also contains small amounts of silicon, manganese, sulphur and phosphorus. Carbon in cast iron usually exists in two forms –

(i) Free carbon or graphite (ii) Combined carbon or cementite.

Since the cast iron is brittle, therefore, it cannot be used in those parts which are subjected to shocks. The properties of cast iron which makes it an important material for engineering purposes are –

(i) High compressive strength (ii) Good casting characteristics
(iii) Wear resistance (iv) Excellent machinability.

Q.5. What is cast iron ? State its composition. ***(R.G.P.V., June 2016)***

Ans. For cast iron, refer Q.4.

Practically speaking there can be a number of types of cast iron, however important of them are –

(i) Grey cast iron (ii) White cast iron
(iii) Malleable cast iron (iv) Nodular cast iron.

Their compositions are given below –

	Grey Cast Iron	White Cast Iron	Malleable Cast Iron	Nodular Cast Iron
Carbon	2.5% – 3.75%	1.75% – 2.3%	2.2% – 3.6%	3.2% – 4.0%
Silicon	1.0% – 2.5%	0.85% – 1.2%	0.4% – 1.1%	1.1% – 3.5%
Manganese	0.4% – 1%	0.1% – 0.4%	0.1% – 0.4%	0.3% – 0.8%
Sulphur	0.06% – 0.12%	0.12% – 0.35%	0.03% – 0.3%	0.2%
Phosphorus	0.1% – 1.0%	0.05% – 0.2%	0.1% – 0.2%	0.08%

Q.6. State the composition of grey cast iron and its applications.* *(R.G.P.V., Dec. 2014)

Ans. Grey cast iron is obtained by allowing the molten metal to cool and solidify slowly. On solidifying, the iron contains the maximum part of carbon in the form of graphite flakes. The grey colour is due to the fact that the carbon is present in the form of free graphite.

Composition – Refer Q.5.

Applications – Some specific applications of grey cast iron are as follows –

(i) Gas or water pipes for underground purposes
(ii) Machine tool structures
(iii) Manhole covers
(iv) Piston rings
(v) Ingot moulds
(vi) Rolling mill and general machinery parts
(vii) House hold appliances
(viii) Frames of electric motors
(ix) Sanitary wares, etc.

Q.7. Describe composition of grey cast iron and its properties and applications in engineering field.* *(R.G.P.V., June 2013)

Ans. For composition and applications of grey cast iron, refer Q.5 and Q.6.

Properties of Grey Cast Iron – Various properties of the grey cast iron are given as follows –

(i) It has a low tensile strength.
(ii) It possesses machinability better than steel.
(iii) It has high resistance to wear.
(iv) It possesses high vibration damping capacity.
(v) It can be readily cast into desired shape.
(vi) Grey cast iron possesses lowest melting point of the ferrous alloys.

(vii) Grey cast iron possesses high fluidity and hence it can be cast into complex shapes and thin sections.

(viii) Grey cast iron possesses excellent casting qualities for producing simple and complex shapes.

Q.8. What is white cast iron ? Give its properties and uses.

Ans. White cast iron is obtained by the presence of relatively large quantities of manganese, a very small amount of silicon and by rapid cooling. White cast iron contains carbon exclusively in the form of cementite.

Properties of White Cast Iron –

(i) White cast iron possesses excellent abrasive wear resistance.

(ii) It is very hard (the hardness ranges from 400 to 600 BHN).

(iii) White cast iron delivers its name from the fact that its freshly broken surface shows a bright white fracture.

(iv) White cast iron under normal circumstances is brittle and not machinable.

(v) The solidification range of white cast iron is 2550-2065°F.

Uses of White Cast Iron –

(i) It is widely used in manufacture of wrought iron.

(ii) For producing malleable iron castings.

(iii) For manufacturing those components which require a hard and abrasion resistant materials.

Q.9. Give uses of malleable cast iron and nodular cast iron.

***Ans.* Uses of Malleable Cast Iron –**

(i) Gear case
(ii) Conveyor chain links
(iii) Rail road
(iv) Universal joint yoke
(v) Automotive crankshaft
(vi) Crankshaft sprocket
(vii) Truck tandem axle assembly parts
(viii) Electrical line hardware.

Uses of Nodular Cast Iron –

(i) Paper industries machinery
(ii) Construction machinery
(iii) Pumps and compressors
(iv) Internal combustion engines
(v) Earth moving machinery
(vi) Farm equipments and tractors
(vii) Valves and fittings
(viii) Power transmission equipments
(ix) Steel mill rolls and mill equipments
(x) Pipes.

Q.10. What is cast iron ? What are different types of cast iron ? Discuss their properties.* *(R.G.P.V., Dec. 2011)

***Ans.* Cast Iron –** Refer Q.4.

Types of Cast Iron – Refer Q.5.

Properties of –

(i) ***Grey Cast Iron*** – Refer Q.7.

(ii) ***White Cast Iron*** – Refer Q.8.

(iii) ***Malleable Cast Iron*** –

(a) Malleable cast iron can be hammered and rolled to obtain different shapes.

(b) Malleable cast iron possesses high yield strength.

(c) It has high Young's modulus and low coefficient of thermal expansion.

(d) It possesses good wear resistance and vibration damping capacity.

(e) It can be used from – 60 to 1200°F.

(f) It has low to moderate cost.

(iv) ***Nodular Cast Iron*** –

(a) Ductile or nodular cast iron possesses very good machinability.

(b) It possesses excellent castability and wear resistance.

(c) The properties of nodular cast iron depend upon the metal composition and the cooling rate.

(d) It possesses damping capacity intermediate between cast iron and steel.

Q.11. Discuss the effect of alloying elements on the properties of cast iron. ***(R.G.P.V., June 2011)***

Or

Discuss the effect of carbon, silicon, phosphorus on the behaviour of cast iron. ***(R.G.P.V., Dec. 2010)***

Ans. **Carbon** – Cast iron contains about 2-4% of carbon. Depending upon the form of carbon available properties of cast iron varies. Carbon in cast iron usually exists in two forms –

(i) Free carbon or graphite

(ii) Combined carbon or cementite.

When iron contains carbon in the graphite form, it is known as grey cast iron. It is easily machinable as free graphite in cast iron acts as a lubricant. Grey cast iron is soft and brittle and may be easily broken under impact load.

In the absence of silicon (or its presence in very little quantity) most of the carbon in cast iron is in the chemically combined form and the iron is called white iron. It is hard and brittle. It cannot be forged or welded. It has low tensile strength and shrinks on cooling.

Silicon – Percentage of silicon present in pig iron varies from 0.5 to 3.0%. Source of silicon in iron is from its presence in any of the raw materials. It tends to make cast iron softer when present in small proportions and makes the iron free from defects like blow holes and oxides. In higher proportions it make cast iron brittle and hard and also renders it resistance to acids also. The most pronounced effect of presence of silicon in small proportions is precipitation of free carbon which is responsible for the softness of cast iron.

Phosphorus – The percentage of phosphorus present in pig iron varies from 0.03 to 2.0%. It combines with iron to form Fe_3P which embrittles cast iron. It lowers the melting point of cast iron and is, therefore, helpful in making thin castings. In larger proportions, its effect is that of retaining carbon in the combined form whereas in smaller proportions, it facilitates precipitation of carbon in the form of graphite. Phosphorus, when present in pig iron, increases the fluidity of molten iron and thus helps in filling the moulds in a better way.

Sulphur – It tends to convert free carbon into combined carbon in the cast iron, which is just the reverse of effect of silicon. As such, higher the proportion of sulphur lesser is the amount of free carbon in cast iron and hence stronger and more brittle is the cast iron. It also accelerates the rate of solidification and promotes the development of sand holes and blow holes. Its percentage is preferably kept below 0.5%.

Q.12. Give the composition, properties and uses of wrought iron. ***(R.G.P.V., June 2010)***

Ans. **Composition** – Wrought iron is the purest form of iron. It contains less than 0.1% carbon. It is a ferrous material and more corrosion resistant than steel.

Wrought iron produced by puddling process contains carbon content less than 0.03%, silicon is about 13%, sulphur is less than 0.02%, phosphorus is about 0.18%, and manganese is less than 0.1%. The wrought iron contains 3% of slag particles distributed in an iron matrix. This slag consists of oxides and silicates of calcium, magnesium, manganese and iron. During rolling the slag particles get elongated in the direction of rolling.

Properties of Wrought Iron – Wrought iron is the purest iron which contains at least 99.5% iron. It contains a large number of minute threads of slag lying parallel to each other, thereby giving a fibrous appearance when fractured. Due to its fibrous structure it gives a prior warning before fracture which makes it most suitable for fatigue loading. The wrought iron is a tough, malleable and ductile material. It cannot withstand sudden and excessive shocks. It can be easily worked and welded at temperature close to its melting point. When cold it is ductile and has good forming qualities. It contains practically no carbon and thus does not get hardened when quenched in water. Its corrosion resistance is even more than the mild steel due to the presence of slags. It can take and hold any protective metal and paint coating.

As wrought iron is free from impurities it is intensely soft. Due to low carbon content its melting point is high and cannot be used as casting alloy. It has very poor mechanical strength and cannot be heat treated to change its physical properties. It can be obtained in the form of plate, sheets, forged billets, structural shapes, bars, piping and tubing.

Uses of Wrought Iron –

(i) Used for pipe making due to its good corrosion and fatigue resistance and better welding and threading qualities.

(ii) Used for making bars for stay bolts, engine bolts and rivets etc., due to its corrosion and fatigue resistance.

(iii) Used for making special chain and crane hooks due to its good weldability and high impact strength.

(iv) Used for making plates.

(v) Also used for general forging applications.

Q.13. Define steel.

Ans. Steel is an alloy of iron and carbon, with the carbon content varies upto 1.5%. The carbon is distributed throughout the metal as a compound (chemical combination) with iron. If the carbon is raised above 1.5%, a stage soon arrives when no more carbon can be obtained in the combined state and any excess must be present as free carbon (graphite). At this stage the metal merges into the group known as cast iron. Therefore, for a material to be classed as steel there must be no free carbon in its composition. Other elements, for example, silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to impart certain desired properties to it.

According to IS : 7598-1974 steels shall be classified as follows –

(i) Unalloyed or plain carbon steels

(ii) Alloy steels.

Q.14. What is carbon steel ? ***(R.G.P.V., Dec. 2016)***

Ans. Carbon steel or also known as plain carbon steel is an alloy of carbon and iron with varying quantities of phosphorus and sulphur. It is defined as a steel which has its properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese.

Q.15. Give the classification of carbon steel. ***(R.G.P.V., June 2014)***

Ans. Carbon steels are alloy of pure iron and carbon. Depending upon the percentage of carbon, they can be classified as –

(i) Low carbon (or mild) steel – 0.05-0.3% C

(a) Dead mild steel – 0.05-0.15% C

(b) Mild steel – 0.15-0.2% C

(c) Mild steel – 0.2-0.3% C

(ii) Medium carbon steel – 0.3-0.6% C

(iii) High carbon steel – 0.6-1.5% C

A special type of high carbon steel containing 0.9-1.5% C is known as tool steel, used for making tools of various machines.

Q.16. Give the composition, properties and uses of mild steel.

Ans. **Composition of Mild Steel –** Refer Q.15 section (i).

Properties of Mild Steel – Various properties of mild steel are given as follows –

(i) It can be easily forged and welded.

(ii) It can be magnetized permanently.

(iii) It has fibrous structure.

(iv) It cannot be hardened and tempered easily.

(v) It cannot be easily affected by hard water.

(vi) It is ductile and malleable.

(vii) It rusts readily.

(viii) Its ultimate compressive strength is about 80 to 120 kN/cm^2.

(ix) Its specific gravity is 7.80.

(x) It is tougher and more elastic than wrought iron.

(xi) Its ultimate tensile and shear strengths are about 60 to 80 kN/cm^2.

(xii) Its melting point is about 1390°C.

Uses of Mild Steel – The uses of mild steel are as follows –

(i) Mild steel containing 0.05 to 0.15% carbon is used for making stampings, wires, rivets, sheets, screws, pipes, thin plates, automobile body, nails and chain.

(ii) Mild steel containing 0.15 to 0.20% carbon has a tensile strength of 420 MPa, is used for making camshafts, sheets and strips for fan blades, universal beams, welded tubing, forgings, drag lines, etc.

(iii) Mild steel containing 0.20 to 0.30% carbon has a tensile strength of 555 MPa and hardness of 140 BHN. It is used for making gears, valves, connecting rods, crankshafts, railway axles, fish plates, small forgings, etc.

Q.17. Discuss in brief medium carbon steel.

Ans. Medium carbon steel contains carbon from 0.3 to 0.60%.

Steel containing 0.3-0.45% carbon has tensile strength of 750 N/mm^2. They have good machinability and good deep hardening properties. They are used for making axles, heavy duty shafts, connecting rods, rails, turbine discs, rotor and gear shafts, etc.

Steel containing 0.45-0.55% carbon has tensile strength of 1000 N/mm^2 and are used for manufacturing parts which have to be subjected to shock and heavy reversal of stress, such as railway coach axles, large size forgings such as crank shafts, gear axles, spline shafts, etc.

Steel containing 0.55-0.60% carbon are used for making drop forging dies, die blocks, plate punch, self tapping screws, valve springs, cushion springs, lock washers, thrust washers, etc.

Q.18. Give the composition, properties and uses of high carbon steel.

Ans. Steel containing 0.60 to 1.5% carbon is known as high carbon steel. They possess wear resistance and high hardness after heat treatment.

Chemical composition of high carbon steel is given as follows –

Material	*Percentage*
Carbon	0.6-1.5
Silicon	0.15-0.3
Manganese	0.15-0.35
Chromium	0.2

Properties – Various properties of high carbon steel are given as follows –

(i) Its ultimate tensile strength is about 80 to 110 kN/cm^2 .

(ii) Its ultimate shear strength is about 110 kN/cm^2.

(iii) Its ultimate compressive strength is about 140 to 200 kN/cm^2.

(iv) Its specific gravity is 7.90.

(v) It can be easily tempered and hardened.

(vi) It can be magnetized permanently.

(vii) It can be easily forged and welded.

(viii) It rusts easily and rapidly.

(ix) It is tougher and more elastic than mild steel.

(x) It has granular structure.

(xi) It cannot be easily affected by salt water.

Uses – Uses of high carbon steel are given as follows –

(i) Steels containing 0.6 to 0.8% carbon are used for making cold chisels,wrenches, automatic clutch discs, etc.

(ii) Steels containing 0.8 to 0.9% carbon are used for making rock drills, punches, dies, railway rails, circular saws, machine chisels, etc.

(iii) Steels containing 0.9 to 1.0 % carbon are used for making springs, keys, pins, etc.

(iv) Steels containing 1.0 to 1.1% carbon are used for making machine tools, mandrels, taps, etc.

(v) Steels containing 1.1 to 1.5% carbon are used for making twist drills, taps, thread metal dies, knives, etc.

Q.19. Write down composition of carbon steel and enlist mechanical properties. ***(R.G.P.V., June 2015)***

Ans. Refer Q.15, Q.16, Q.17 and Q.18.

IRON-CARBON DIAGRAM

Q.20. What do you mean by iron-carbon equilibrium diagram ? Give its limitations.

Ans. An equilibrium or phase or constitutional diagram is a graphic representation of the effects of temperature and composition upon the phase present in an alloy. Such a diagram for iron-carbon alloys showing variation of carbon content with the temperature is called iron-carbon equilibrium diagram. Since any iron-carbon alloy in the molten state may be considered as a solution of iron carbide (Fe_3C) in iron, therefore an iron-carbon equilibrium diagram can also be called as iron-iron carbide equilibrium diagram.

Limitations of Iron-carbon Equilibrium Diagram – Iron-carbon diagram has the following limitations –

(i) This diagram does not show time as a variable. It shows only the phases and the resulting microstructures corresponding to equilibrium conditions.

(ii) It cannot show the effects of various cooling rates upon the structure of various grades of steel.

(iii) Iron-carbon equilibrium diagram is of only limited use in the study of steel cooled under non-equilibrium conditions.

Q.21. Sketch the iron-carbon equilibrium diagram and point out its salient features. ***(R.G.P.V., Dec. 2015)***

Or

Discuss the iron-carbon diagram and various allotropies of steel. ***(R.G.P.V., Dec. 2011)***

Or

Draw a neat sketch of iron-carbon equilibrium diagram and explain various reactions involved. ***(R.G.P.V., Dec. 2010)***

Or

Explain the steel and iron-carbon diagram. ***(R.G.P.V., June 2014)***

Or

Explain the iron-carbon diagram. ***(R.G.P.V., Dec. 2014)***

Or

Draw an iron-carbon diagram for steel. ***(R.G.P.V., June 2016)***

Ans. Fig. 1.1 shows an iron-carbon equilibrium diagram since any iron carbon alloy in the molten state may be considered as a solution of iron carbide Fe_3C in iron. Therefore, it is also called as iron-iron carbide equilibrium diagram.

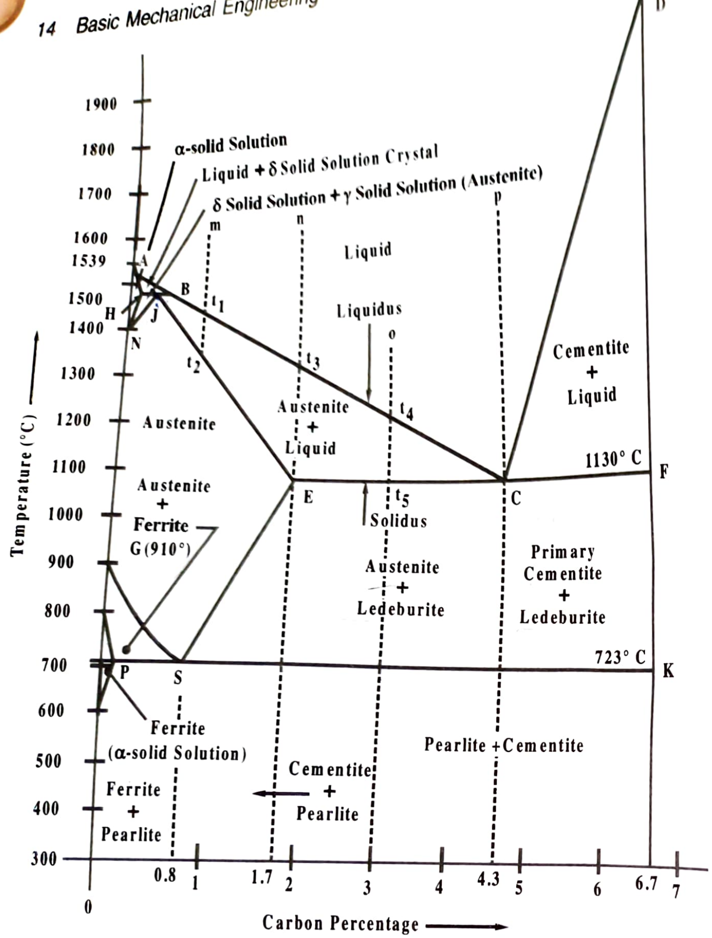


Fig. 1.1 Iron-carbon Equilibrium Diagram

An equilibrium phase or constitutional diagram is a graphic representation of the effects of temperature and composition upon the phase present in an alloy.

An equilibrium diagram is constructed by plotting temperature along y-axis and percentage composition of the alloy along the x-axis. This diagram shows ranges of temperatures and compositions within which the various phase changes are stable and also the boundaries at which the phase changes occur.

Iron-carbon equilibrium diagram indicates the phase changes that occur during heating and cooling and the nature and amount of structural components that exist at any temperature. Besides, it establishes a correlation between the microstructure and properties of steel and cast irons and provides a basis for the understanding of the principles of heat treatment.

An iron-carbon equilibrium diagram forms a basis for differentiating among iron (0.008% C or less), hypoeutectoid steels (0.008 to 0.8% C), hypereutectoid steels (0.8 to 2.0% C), hypoeutectic cast irons (2 to 4.3%C) and hypereutectic cast iron above 4.3% carbon.

The iron-carbon equilibrium diagram has a peritectic point J, an eutectic point C and an eutectoid point S.

All alloys represented in region above ABCD are completely liquid. Alloys containing carbon upto 4.3% when cooled to temperature on the curve ABC, solid crystals begin to form. ABC is thus called liquidus for these alloys. While alloys containing more than 4.3% carbon starts to solidify along the line CD liquidus for these alloys. These alloys completely solidify when cooled to a temperature of 1130°C, but alloys containing carbon upto 4.3% solidify completely along the line HJEC called solidus.

Total transformation which takes place in the carbon equilibrium diagram can be divided into two types of transformations –

(i) Primary transformation – Transformation from the liquid to the solid state.

(ii) Secondary transformation – Transformation in the solid state.

(i) Primary Transformation – In this transformation liquid alloys of various carbon content are cooled just below the eutectic temperature 1130°C so that they convert into solid.

Consider cooling of an alloy containing 0.8% carbon started to cooled from a temperature of 1600°C, shown by point m on the diagram above the liquidus line ABC, it will remain liquid until it is cooled to a temperature t_1 on liquidus. At this point, crystal of austenite of composition m begins of precipitate from the liquid alloy. When temperature is decreased further the amount of austenite increases along the line HJE. At temperature t_2 percentage of carbon on solidus curve HJE will be 0.8% same as of original alloy, the alloy solidifies completely and contains only austenite.

Consider another alloy containing 1.7% carbon shown by point n on the diagram. Similar process as discussed above will take place. The austenite crystals will begin to precipitate at temperature t_3 on liquidus. Liquid become richer in carbon as austenite separating at eutectic temperature (1130°C) last drop of liquid containing 1.7% carbon will solidify. Solidified alloy consists entirely austenite containing 1.7% C dissolved in solid solution of γ-iron.

Consider another alloy containing 3% carbon shown by point O on the diagram is cooled slowly. It begins to form austenite at a temperature t_4 on liquidus. The amount of austenite continuously increases with the temperature fall. When temperature reaches to 1130°C shown by t_5 on solidus, the alloy will be completely solidified. Austenite formed at 1130°C is called primary austenite. From this saturated austenite crystals precipitate simultaneously with cementite and form eutectic mixture ledeburite.

An alloy contains 4.3% carbon cools from a temperature corresponds to point p on the diagram will remain liquid to the temperature 1130°C (eutectic temperature). At this temperature alloy will solidify completely and forms eutectic mixture ledeburite (saturated mixture of austenite and cementite). At this point liquid phase is in equilibrium with two solid phases. The system with three phases in a two component system will have zero degrees of freedom. Thus, the liquid will solidify at constant temperature along CF.

Alloys containing more than 4.3% carbon forms cementite on solidification. When eutectic temperature is reached alloy will solidify at this constant temperature and forms solid eutectic of saturated austenite and cementite.

(ii) ***Secondary Transformation*** – Transformations which occur in solid state are called secondary transformations. Temperatures at which structural changes in steel on heating and cooling occur are called ***critical points*** or ***arrest points***. They are designated by symbols A_c for heating and A_r for cooling. Where A stands for arrest, c stands for chauffage (heating) and r for refroidissment (cooling). Secondary transformation is more illustrated in fig. 1.2.

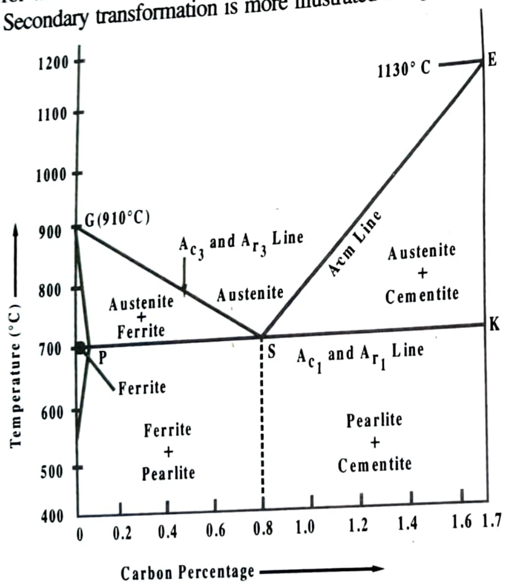


Fig. 1.2

Consider an alloy with 0.3% carbon is cooled from a temperature above the line GS, in fig. 1.2. Nothing will happen till 800°C, at this temperature g-iron in austenite begins to transform into α-iron. Ferrite crystals will form and amount of austenite will increase along line GS. A_{c_3} and A_{r_3} represent the critical points in heating and cooling on line GS. At temperature 723°C corresponds to point S (eutectoid point) austenite decomposes and form pearlite

(eutectoid mixture of ferrite and cementite). Pearlite consists alternating layers of cementite and ferrite. Temperature at which pearlite is formed designated as A_{r_1} on line PSK and temperature at which pearlite transforms into austenite on heating is designated as A_{c_1}.

Steels containing exactly 0.8% carbon will exhibit no change until the eutectoid point S is reached. The further cooling will cause complete transformation of the eutectoid austenite into pearlite. Steel containing more than 0.8% carbon when cooled to curve SE (known as Acm line) their austenite decomposes and excess carbon precipitates as cementite. As cementite is rich in carbon (contains 6.67% carbon), its separation will cause decrease in carbon content of austenite. When eutectic temperature (723°C) is reached, remaining austenite (having 0.8% carbon) will transform into pearlite at this constant temperature.

Q.22. Explain the following reactions in relation to iron-carbon equilibrium diagram –

(i) Eutectic reaction (ii) Eutectoid reaction (iii) Peritectic reaction.

(R.G.P.V., Dec. 2012, 2015)

Ans. (i) Eutectic Reaction – The eutectic reaction takes place at 1130°C and its equation may be written as

$$\text{Liquid} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \underbrace{\text{Austenite + Cementite}}_{\substack{\text{Eutectic mixture} \\ \text{(Ledeburite)}}}$$

Eutectic point is at 4.3% carbon. Eutectic mixture is not usually seen in the microstructure, because austenite is not stable at room temperature and must undergo another reaction during cooling.

(ii) ***Eutectoid Reaction*** – In iron-carbon equilibrium diagram, the eutectoid reaction is represented by the horizontal line of 723°C and point S marks the eutectoid point. The eutectoid equation may be written as

$$\text{Solid} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \underbrace{\text{Ferrite + Cementite}}_{\substack{\text{Eutectoid mixture} \\ \text{(Pearlite)}}}$$

(iii) ***Peritectic Reaction*** – In iron-carbon equilibrium diagram the peritectic point is shown by point J.

Peritectic reaction equation may be written as

$$\text{Delta } (\delta) + \text{Liquid} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \text{Austenite}$$

The horizontal line at 1500°C shows the peritectic reaction.

ALLOYS STEELS AND THEIR APPLICATIONS

Q.23. What are alloy steels ? Why alloying is done ? Explain. ***(R.G.P.V., June 2013)***

Ans. An alloy steel may be defined as steel to which elements other than carbon are added in sufficient amount to produce improvements in steel. Commonly used alloy elements are nickel, chromium, manganese, silicon, molybdenum, vanadium, phosphorus, tungsten, titanium, copper, zirconium, cobalt and aluminium. These elements may be used separately or in combination according to the desired characteristics in the steel. Each of these elements confer certain qualities upon the steel to which it is added.

Purposes of Alloying – Alloying is done for specific purposes which are as follows –

(i) To increase wear resistance and corrosion resistance.
(ii) To improve hardness, toughness and tensile strength.
(iii) To improve machinability.
(iv) To improve low or high temperature stability.
(v) To improve case hardening properties.
(vi) To improve cutting ability.

Q.24. Give advantages and disadvantages of alloy steels.

Ans. **Advantages of Alloy Steel –**

(i) Greater ductility at high strength.
(ii) Greater high temperature strength.
(iii) Greater hardenability.
(iv) Less grain growth.
(v) Less distortion and cracking.
(vi) Higher elastic ratio and endurance strength.

Disadvantages of Alloy Steel –

(i) High cost.
(ii) Requires special handling.
(iii) Temper brittleness in certain grades.
(iv) Tendency toward austenite retention.

Q.25. State the effects of adding the alloying elements such as manganese and tungsten to steels. ***(R.G.P.V., June 2015)***

Or

State the effects of adding the following alloying elements to steels –
(i) Manganese (ii) Tungsten
(R.G.P.V., March/April 2010)

Ans. ***(i) Manganese –***
(a) Counteracts the effect of sulphur (i.e., brittleness).
(b) Steel containing 11-14% manganese are resistant to wear, work harden easily and are resistant to abrasion under shock.

(ii) Tungsten –
(a) It increases cutting hardness and magnetic retentivity.
(b) Refines the grains.
(c) It resists heat.

Q.26. State the effects of adding various alloying elements on properties of steel.

Ans. The effects of addition various alloying elements on properties of steel are given below as follows –

(i) Boron –
(a) It improves hardness and mechanical properties.
(b) It also improves rolling qualities of steel.

(ii) Copper –
(a) Improves atmospheric corrosion resistance.
(b) Acts as a strengthening agent.

(iii) Aluminium –
(a) Used as an effective deoxidiser.
(b) Controls grain growth.
(c) Increases surface hardness.

(iv) Nickel –
(a) Increases hardness, toughness and impact strength at low temperature.
(b) Improves response to heat treatment especially in large sections.
(c) Improves elasticity, resistance to fatigue and corrosion.

(v) Chromium –
(a) It forms a complex series of chromium carbides and thus improves the hardenability and increases resistance to abrasion and wear.
(b) Combination of nickel and chromium improves the mechanical properties of steel.

(vi) Manganese – Refer Q.25, Section (i).

(vii) Molybdenum –
(a) Molybdenum joins with carbon and promotes hardenability.
(b) Steel containing chromium and nickel suffer from temper brittleness, this difficulty can be overcome by adding 0.25% molybdenum.
(c) Raises tensile and creep strength at high temperatures.

(viii) Cobalt –
(a) Improves mechanical properties such as tensile strength, fatigue strength and hardness.
(b) Improves heat resistance.

(ix) *Sulphur* –

(a) Lowers the toughness and transverse ductility.

(b) Imports brittleness to chips removed in machining operation.

(x) *Tungsten* – Refer Q.25, section (ii).

(xi) *Silicon* –

(a) It removes oxygen in steel making.

(b) Increases strength without decreasing ductility.

(xii) *Vanadium* –

(a) It gives strength and toughness to steel.

(b) It improves the hardening quality of steel.

(c) Used for providing a fine grained structure over a wide range of temperature.

(xiii) *Titanium* –

(a) Prevents precipitation of chromium carbide.

Q.27. What is alloy steel ? Name two types of alloy steel giving their composition and uses. ***(R.G.P.V., June 2012)***

***Ans.* Alloy Steel** – Refer Q.23.

Types of Alloy Steels –

(i) Manganese Steel – Small amount of manganese is used in almost all steels to deoxidise the molten steel during manufacture. Manganese also mitigate the brittleness caused by sulphur. The various types of steel can be classified into 3 main types –

(a) Steels with 1-2% Mn, 0.2-0.55% C. This type of steel has a combination of high strength and toughness. They are used in automobile manufacture, locomotive axles, connecting rods and also in riffle barrels.

(b) Steels with 8% Mn and 0.9% C. It is a very useful non-deforming tool steel, used for manufacture of various machine tools.

(c) Steels with 10-14% Mn and upto 1.3% C, are very hard and have no ductility before heat treatment. When rapidly hardened by cold working develop great resistance to wear, makes them very difficult to machined. They are used in machine parts subjected to shock and excessive wear such as railway and tramway points, jaws of stone crushing machines, bullet proof helmets, etc.

(ii) Nickel Steel – These are the most widely used alloy steels. Content of nickel can vary from 2.5-8.0% with carbon ranging 0.1-0.5%.

Properties – (a) As nickel lowers the critical point heat treatment of this type of steel is less severe.

(b) It has greater tensile strength and elastic limit together with considerable ductility and toughness.

Uses – (a) Nickel steels with 0.1-0.15% carbon and 2.5-3.5% nickel are used for pipe, sheets and rivets.

(b) Steels with C = 0.2-0.4%, Ni = 3.5% are used for highly stressed parts like bevel gears, shafts, air screws, bolts, connecting rod bolts, structural material for bridges, turbine blades and aeroplane parts.

(c) Steels with higher nickel content are used in valves of I.C. engines, electric resistance wires, precision measuring tapes and surveying instruments.

Q.28. Give specific properties and applications of chromium steel.

Ans. Chromium is one of the most commonly using alloying elements, it may be used alone or in conjunction with other elements. Chromium in steel exists in the form of carbide.

Properties – Due to presence of chromium in carbide form, it has high hardness, elastic limit and tensile strength. It also has good ductility due to toughness brought up by fine grained structure. Chromium steels also have a high compressive strength.

Uses – (i) Steels with 1-2% Cr, and 0.15% C are used for ball bearing and roller bearings.

(ii) Steels with 1% Cr and 0.9% C are used for twist drills, hacksaw blades, knives, hammers, etc.

(iii) Steels with 1.5% Cr are used for making springs.

Q.29. What are the composition, properties and uses of high speed steel ? State its various types. ***(R.G.P.V., Dec. 2010)***

Ans. As the name indicates, high speed steel is used for high speed cutting tools.These steels can be divided into two groups depending upon the principal alloying element. The first group is called tungsten high speed steels and is designated by T-series. Steels of this group contain high amount of tungsten with addition of chromium, vanadium and cobalt. The second group of high speed steels is called molybdenum steels. In addition to molybdenum, they also contain tungsten, chromium, vanadium and cobalt. This group is designated by M-series.

Composition – The composition of high speed steels is as follows –

S.No.	*Type*	*%C*	*%Cr*	*%W*	*% Mo*	*%V*	*%Co*
(i)	T_1	0.70	4.00	18.00	–	1.00	–
(ii)	T_2	0.85	4.00	18.00	–	2.00	–
(iii)	T_4	0.75	4.00	18.00	–	1.00	5.00
(iv)	T_5	0.80	4.00	18.00	–	2.00	8.00
(v)	M_1	0.80	4.00	1.50	8.00	1.00	–
(vi)	M_2	0.85-1.00	4.00	6.00	5.00	2.00	–
(vii)	M_6	0.80	4.00	4.00	5.00	1.50	12.00
(viii)	M_{34}	0.85	4.00	2.00	8.00	2.00	8.00

Properties – Various properties of high speed steels are given as follows –

(i) The main characteristic of high speed steel is that it maintains high hardness at temperature upto 550°C.

(ii) They possess high wear resistance.

(iii) It is hard steel and cannot be machined by ordinary methods.

(iv) It allows the tool to cut the metal at high speed.

Uses – The uses of high speed steel include –

(i) Hand tools, such as chisels, punches, hammers, etc.

(ii) Machine tools for cutting metals.

(iii) Shears for cutting materials.

(iv) Dies for deep drawing, extrusion, forging, etc.

(v) For the manufacturing of drills, milling cutters, hobs, broaches, saws, reamer, etc.

Types – High speed steels can be of following types –

(i) 18-4-1 High Speed Steel – This steel, contains about 18% tungsten, 4% chromium and 1% vanadium. It is one of the best all purpose tool steels. It is widely used for drills, lathe, planner and shaper tools, milling cutters, reamers, broaches, threading dies, punches, etc.

(ii) Molybdenum High Speed Steel – This steel contains about 6% tungsten, 6% molybdenum, 4% chromium and 2% vanadium. It is better and cheaper than other types of steels. It has excellent toughness and cutting ability and particularly used for drilling and tapping operations.

(iii) Super High Speed Steel – This steel contains 20% W, 4% Cr, 2% V and 12% Co. Due to high cobalt content, it is also called cobalt high speed steel. Cobalt increases its cutting efficiency especially at high temperatures. Due to its high cost, this steel is used for heavy cutting operations which impose high pressure and temperatures on the tool.

(iv) Vanadium High Speed Steel – This steel contains more than 1% V. It has better abrasive resistance than 18-4-1 steel. It is generally used for machining difficult to machine materials.

Q.30. State the material used for making of the following parts, stating reason – twist drill, milling cutter. (R.G.P.V., Dec. 2015)

Ans. Twist drill and milling cutters are usually made of 18-4-1 high speed steels containing 18% tungsten, 4% chromium and 1% vanadium. This type of steel has excellent red hardness, good wear resistance, fair machinability, high compressive strength and good cutting ability.

Q.31 State various alloy steels with applications.(R.G.P.V., June 2016)

Ans. Refer Q.27, Q.28 and Q.29.

Q.32. What is stainless steel ? Describe main properties and composition in brief. (R.G.P.V., March/April 2010)

***Ans.* Stainless Steel –** Stainless steel is an iron base alloy which has a great corrosion resistance. It has been found that when chromium content is 11.5% or more a fine film of chromium oxide forms spontaneously on the surface. This film acts as a barrier to retard further oxidation, rust or corrosion. This steel cannot be stained easily, hence called stainless steel. It is thus ideally suited for handling and storage of liquid helium, hydrogen, nitrogen and oxygen that exist at cryogenic temperature.

Stainless steel can be classified into following three groups on the basis of their microstructure –

(i) Austenitic Stainless Steel –

Composition – These steels contain 0.03 to 0.25% C, 2 to 10% Mn, 1 to 2% Si, 16 to 26% Cr and 3.5 to 22% Ni. Mo and Ti are also added in some cases.

Properties – (a) These steels possess austenitic structure at room temperature because of containing Ni.

(b) These steels possess greatest strength and scale resistance at high temperature.

(c) These steels are non-magnetic and possess greatest resistance to corrosion and good mechanical properties at elevated temperature.

(d) These steels can be easily welded.

(e) These steels are very tough and can be forged and rolled but offer great difficulty in machining.

Uses – (a) These steels are extensively used in chemical processing, paper making and dairy industries.

(b) Used in engine parts of aircrafts, trailers and railway cars, etc.

(ii) Martensitic Stainless Steel –

Composition – These steels contain 0.15 to 1.2%C, 1% S; 1% Mn and 11.5 to 18% Cr.

Properties – (a) These steels possess martensitic structure.

(b) These steels are magnetic in all conditions and possess the best thermal conductivity of the stainless types.

(c) These steels can be easily welded and machined.

(d) Ductility, hardness and ability to hold an edge are characteristics of these steels.

(e) These steels can be cold worked without difficulty.

(f) These steels have good toughness and show good corrosion resistance to weather.

Uses – (a) These steels may be used where the conditions are not too severe such as for hydraulic, steam and oil pumps, valves and other engineering components.

(b) These are also used for cutlery, springs, surgical and dental instruments.

(iii) Ferritic Stainless Steel –

Composition – These steels contain 0.08 to 0.20% C, 1% Si, 1 to 1.5% Mn and 11 to 27% Cr.

Properties – (a) These steels possess a ferritic microstructure.

(b) These steels are magnetic and have good ductility.

(c) These steels are more corrosion resistant than martensitic steels.

(d) These steels do not work harden to any appreciable degree.

(e) These steels develop their maximum softness, ductility and corrosion resistance in the annealed condition.

(f) These steels have lower strength at elevated martensitic steels.

Uses – (a) These steels are mainly used as sheet or strip for cold forming and pressing operations for purposes where moderate corrosion resistance is required.

(b) These steels are widely used for pump shafts, spindles and valves as well as for many other fitting where a good combination of mechanical and corrosion properties are required.

Q.33. Define steel. Discuss its various types, uses and their applications. ***(R.G.P.V., June 2011)***

Ans. Refer Q.13, Q.15, Q.16, Q.17, Q.18, Q.32 and Q.27.

MECHANICAL PROPERTIES LIKE STRENGTH, HARDNESS, TOUGHNESS, DUCTILITY, BRITTLENESS, MALLEABILITY, ETC. OF MATERIALS

Q.34. Name various mechanical properties of materials.

Ans. The properties of material which are associated with the ability of the material to resist mechanical forces and loads, are known as mechanical properties. Some important mechanical properties of materials are –

(i) Strength	(ii) Stiffness	(iii) Elasticity
(iv) Plasticity	(v) Ductility	(vi) Brittleness
(vii) Malleability	(viii) Hardness	(ix) Machinability
(x) Resilience	(xi) Toughness	(xii) Fatigue
(xiii) Creep		

Q.35. Define stress and strain. ***(R.G.P.V., June 2015)***

Ans.* Stress –** When some external forces are applied to a body, it offers resistance to these forces. The magnitude of this resisting force is numerically equal to the applied forces. This internal resisting force per unit area is called ***stress. Therefore, stress can be defined as the intensity of internal forces resisting change in the shape of the body. It is calculated by simply dividing the force acting on an area divided by the area. It is measured in N/m^2 or kg/cm^2. Mathematically,

$$\text{Stress,} \quad \sigma = P/A$$

where, P = Force applied, A = Cross-sectional area.

Strain – Strain is defined as the deformation or change produced in the dimensions of a body due to the effect of stress on it. It is a ratio of the change in dimension to the original dimension. Mathematically,

$$\text{Strain,} \quad \varepsilon = \frac{\text{Change in length}}{\text{Original length}} = \frac{\delta l}{l}$$

Strain is a dimensionless quantity.

Q.36. Define ductility and malleability with suitable examples. ***(R.G.P.V., March/April 2010)***

***Ans.* Ductility –** It is the property of a material which enables it to draw into the shape of wire. Mild steel is an example of ductile material. The percentage elongation and the reduction in area in tension is often used as empirical measure of ductility.

$$\%\,\text{Elongation} = \frac{\text{Final gauge length} - \text{Original gauge length}}{\text{Original gauge length}} \times 100$$

$$\%\,\text{Reduction in area} = \frac{\text{Original area} - \text{Final area}}{\text{Original area}} \times 100$$

A material is generally said to be ductile if the percentage elongation is more than 5 in a gauge length of 50 mm. Mild steel, copper, aluminium, zinc, nickel, tin, etc., are ductile metals.

Malleability – This is the property by virtue of which a material may be hammered or rolled into thin sheets without rupture. This property increases with increase of temperature. Aluminium, copper, tin, lead, steel, etc., are malleable metals.

Q.37. Explain the difference between malleability and ductility. ***(R.G.P.V., June 2014)***

Ans. The differences between ductility and malleability are given below –

S.No.	Ductility	Malleability
(i)	Ductility is the ability of a material to undergo deformation under tension without rupture.	Malleability is the capacity of a material to withstand deformation under compression without rupture.
(ii)	It is the property of material by virtue of which it can be drawn into wires.	It is the property by virtue of which a material may be hammered or rolled into thin sheets.
(iii)	It is a tensile property.	It is a compressive property.
(iv)	Ductility depends upon the grain size of the metal crystal.	Malleability depends upon the crystal structure of material.
(v)	Examples – Mild steel, copper, aluminium, zinc, nickel, tin, etc.	Examples – Gold, silver, aluminium, tin, zinc, wrought iron, etc.

Q.38. Define hardness. How it can be measured ? (R.G.P.V., June 2016)

Or

Define hardness. Name various hardness tests.

(R.G.P.V., March/April 2010)

Ans. Hardness is the property of material by virtue of which it is able to resist wear and plastic deformation usually by indentation. Hardness also means the ability of a material to cut another material. The hardness of the material depends upon the type of bonding forces between atoms, ions or molecules and increases with the magnitude of these forces. Thus molecular solids such as plastics are relatively soft, metallic and ionic solids are harder and covalent solids are the hardest materials known.

Diamond is the hardest substance known, while other hard substances are corundum, topaz, quartz, high carbon iron, etc.

Hardness of a material can be measured by means of following tests –

(i) Brinell hardness test

(ii) Rockwell hardness test

(iii) Vickers hardness test.

The hardness of a material can be increased by alloying, cold working and precipitation hardening.

Q.39. Define the following mechanical properties of engineering material –

(i) Ductility (ii) Brittleness (iii) Toughness.

(R.G.P.V., Dec. 2011)

Ans.(i) Ductility – Refer Q.36.

(ii) Brittleness – Brittleness of a material is the property of breaking without much permanent distortion. In other words, lack of ductility is brittleness. If a body breaks easily when subjected to shocks it is said to be brittle. Such materials are glass, cast iron, etc.

(iii) Toughness – Toughness is the strength with which the material opposes rupture. It is a measure of the amount of energy, a material can absorb before actual fracture or failure takes place. Mild steel is tougher than glass.

Q.40. Define the term stiffness.

Ans. Stiffness is defined as the resistance of a material to elastic deformation or deflection. It is also called rigidity. A material which suffers more deformation under load has a low degree of stiffness or rigidity. For example, suspended beams of aluminium and steel may both sufficiently strong to carry the required load but the aluminium beam will bend or deflect further. In other words, the aluminium beam is less stiffer than steel beam. If the material follows Hook's law, its stiffness or rigidity is measured by the Young's modulus E. The higher the value of Young's modulus, the stiffer the material.

In compressive and tensile stress, it is known as modulus of elasticity or modulus of stiffness; in volumetric distortion, it is called the bulk modulus. The term flexibility is sometimes used as the opposite of stiffness.

Q.41. Define the following mechanical properties of an engineering material –

(i) Hardness (ii) Toughness (iii) Fatigue. (R.G.P.V., Dec. 2012)

Ans. (i) Hardness – Refer Q.38.

(ii) Toughness – Refer Q.39, section (iii).

(iii) Fatigue – The term fatigue is used to describe the behaviour of materials under variable loading. When a material is subjected to thousands or even millions of cyclic load applications in which the maximum stress developed in each cycle is well within the elastic range of the material, it has been found that material gets failed at a stress well below than its yield point stress. The failure is caused by means of progressive crack formation which is usually fine and of microscopic size.

The maximum stress which can be applied to a material for indefinite number of times without causing failure, is known as ***fatigue strength.***

Almost all kinds of machine members are subjected to variable loading e.g., motor shafts, bolts, springs, valves, automobile and gas engine parts, suspension bridges, turbine blades, aeroplanes, pressure vessels, etc. The importance of fatigue phenomenon can be assessed from the fact that 80-90% of the total failure of high speed machine parts is due to fatigue.

Q.42. Define the following mechanical properties of engineering material –

(i) Ductility *(ii) Hardness*
(iii) Toughness *(iv) Machinability.*

(R.G.P.V., June 2012)

Ans.(i) ***Ductility*** – Refer Q.36.

(ii) ***Hardness*** – Refer Q.38.

(iii) ***Toughness*** – Refer Q.39, section (iii).

(iv) ***Machinability*** – Machinability of a material indicates the ease with which it can be cut or removed by cutting tools in various machining operations. It depends upon the chemical composition, microstructure and physical properties of the material and the cutting conditions. Soft materials like copper, mild steel and aluminium have good machinability, while hard materials like white cast iron have very less machinability.

Q.43. Define the following properties of material – ductility, toughness, hardness, creep. ***(R.G.P.V., Dec. 2015)***

Ans. **Ductility** – Refer Q.36.

Toughness – Refer Q.39, section (iii).

Hardness – Refer Q.38.

Creep – When a machine part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation, which is called as ***creep***. It is not necessary that creep occurs only at high temperatures, it has also been observed to occur at low temperatures. But elevated temperatures greatly increases the creep deformation rate, specially when the temperature is in the vicinity of half of the melting point, creep rate increases greatly. Deformation caused by creep may ultimately cause the failure of material. Failure due to creep may be defined either by separation in two parts by rutpure or attainment of a specified strain at which a machine component fails to perform its function.

Q.44. Explain the various mechanical properties of material.

(R.G.P.V., Dec. 2016, 2017)

Or

Describe the various mechanical properties of materials in short.

(R.G.P.V., June 2011)

Ans. The material properties which are associated with the ability of the material to resist mechanical forces and loads are known as mechanical properties. The mechanical properties are a measure of the strength and lasting characteristics of a material in service. Some important mechanical properties are described below –

(i) ***Strength*** – The resistance offered by a material on application of external force or load is known as strength. Depending on the type of load applied, the strength could be compressive, tensile or shear.

(ii) ***Elasticity*** – Elasticity of a material is its power of coming back to its original position after deformation when the stress or load is removed.

In other words, elasticity is that property of a material by virtue of which deformation caused by applied load disappears upon removal of the load. Elasticity is a tensile property of the material.

(iii) Plasticity – The plasticity of a material is its ability to undergo some degree of permanent deformation without rupture or failure. The plastic deformation takes place beyond the elastic limit. This property of a material is important in forming, extruding, shaping and many other cold or hot working processes. Generally, plasticity decreases with decreasing temperature. Material such as steel is plastic at bright heat and lead, clay, etc., are plastic at room temperature.

(iv) ***Stiffness*** – Refer Q.40. Tenth Plastic

(v) ***Ductility*** – Refer Q.36.

(vi) ***Malleability*** – Refer Q.36.

(vii) ***Toughness*** – Refer Q.39, section (iii).

(viii) ***Brittleness*** – Refer Q.39, section (ii).

(ix) ***Hardness*** – Refer Q.38.

(x) ***Fatigue*** – Refer Q.41, section (iii).

(xi) ***Creep*** – Refer Q.43.

(xii) ***Resilience*** – Resilience is the capacity of a material to absorb energy elastically. On removal of the load, the energy stored is given off exactly as in spring. ***Proof resilience*** is defined as the maximum energy which can be stored in a material upto elastic limit. ***Modulus of resilience*** is defined as the proof resilience per unit volume. In other words, the modulus of resilience is defined as the amount of energy required to stress unit volume of a material to its proportional limit. The quantity gives capacity of the material to bear vibrations and shocks.

(xiii) Wear – In case of relative motion between two surfaces, the surface material get detached in the form of small particles. This type of depletion of material is known as wear. Wear depends upon surface finish, temperature, hardness, lubrication arrangement, presence of foreign matter and speed of relative motion.

TENSILE TEST – STRESS-STRAIN DIAGRAM OF DUCTILE AND BRITTLE MATERIALS, HOOKE'S LAW AND MODULUS OF ELASTICITY

Q.45. What is the purpose of testing engineering materials ? ***(R.G.P.V., Dec. 2015)***

Ans. Engineering materials used in structures, machines and various other products are subjected to load and deformation. To ensure their safe working of structures and machines, engineering properties of materials are required to determine very precisely. Engineering materials are tested for one or more of the following purposes –

(i) To determine the fundamental mechanical properties like ductility, malleability, toughness, hardness, fatigue, creep, etc.

(ii) To check chemical composition.

(iii) To determine the tensile, shear and impact strength of material when subjected to load.

(iv) To determine the surface defects in raw materials or processed parts.

(v) To ascertain suitability of a material for a particular application.

Q.46. How tensile test is conducted ? ***(R.G.P.V., Feb. 2010)***

Ans. The tensile test is one of the most widely used of the mechanical tests. To conduct the tensile test dimension and shape of specimen depends upon the shape and size of the original material. The cross-section of specimen is shown in fig. 1.3. Standard gauge length used most commonly is given by

$$\boxed{L_0 = 5.65\sqrt{A_0} = 5.0\, d_0}$$

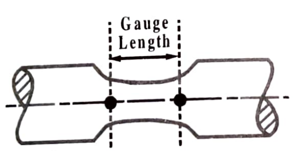


Fig. 1.3 Specimen for Tensile Test

where, A_0 = Area of cross-section in mm^2

d_0 = Diameter of cross-section in mm.

This specimen is gripped in jaws of universal testing machine and tensile load is applied. With the increase in the load the length of the specimen increases. The increase in the length (or elongation) of the specimen depends upon the load applied. Tensile test is conducted to study about the behaviour of material under uniform stressing. A stress-strain curve is made during the tensile testing of a polycrystalline metal specimen.

Now if we plot a graph with stress (i.e., load divided by the original cross-sectional area of the specimen) along the vertical axis and corresponding strain

(i.e., elongation or change in length divided by the original gauge length) along the horizontal axis. Such a curve is known as stress-strain diagram (shown in fig. 1.4) for a ductile material. Stress-strain diagrams are used for estimation of –

(i) Ultimate strength of the material

(ii) Yield point and yield strength of the material

(iii) % elongation

(iv) Young's modulus

(v) Ductility

(vi) Stiffness

(vii) Resilience

(viii) Toughness.

Q.47. Define tensile strength for a material. ***(R.G.P.V., Dec. 2014)***

Ans. Tensile strength of a material can be defined as the maximum value of tensile stress, under a steady load which a material can withstand before fracture. It is calculated by dividing the maximum load by the original cross-section area, i.e.

$$\text{Tensile strength} = \frac{\text{Maximum tensile load}}{\text{Original cross-section area}}$$

Tensile strength is also called as ultimate tensile strength or ultimate strength. It is taken as a basis for fixing the working stresses, especially in brittle materials. Its units are same as those of stress, i.e. kg/cm^2 or N/mm^2 or Pa.

Q.48. State and explain Hooke's law and modulus of elasticity. ***(R.G.P.V., June 2015)***

Or

Explain the Hooke's law. ***(R.G.P.V., Dec. 2016)***

Or

Write short note on – Hooke's law and modulus of elasticity. ***(R.G.P.V., Feb. 2010)***

Or

Describe Hooke's law and modulus of elasticity. ***(R.G.P.V., March/April 2010)***

Ans. According to Hooke's law, when a material is loaded within its elastic limit, the stress is proportional to strain, or in other words, within elastic limits the ratio of stress in a material to the strain produced remains constant. Mathematically,

$$\frac{\text{Stress}}{\text{Strain}} = \text{Constant}$$

i.e.,

$$\frac{\sigma}{\varepsilon} = E$$

where E is a constant of proportionality, which is called as a ***modulus of elasticity*** or ***Young's modulus***. It has same unit as the stress, i.e. N/m^2 or kg/cm^2.

Q.49. What is modulus of elasticity ? Give its unit of measurement. ***(R.G.P.V., Dec. 2014)***

Ans. Refer Q.48.

Q.50. Explain the following –
(i) Hooke's law (ii) Modulus of elasticity (iii) Tensile test of steel.
(R.G.P.V., June 2016)

Ans. Refer Q.48 and Q.46.

Q.51. Define following properties of engineering materials –
(i) Hardness (ii) Ductility
(iii) Fatigue (iv) Modulus of elasticity.
(R.G.P.V., June 2013)

Ans. *(i)* ***Hardness*** – Refer Q.38.

(ii) ***Ductility*** – Refer Q.36.

(iii) ***Fatigue*** – Refer Q.41, section (iii).

(iv) ***Modulus of Elasticity*** – Refer Q.48.

Q.52. What is stress-strain diagram ?

Ans. When a material is loaded or stressed, it gets deformed or subjected to strain. To understand the variation of strain with applied stress, a stress-strain diagram is plotted. To plot a stress-strain diagram, a material is gripped in a universal testing machine and the load is applied, and the corresponding deformation is noted. The process is repeated with continuously increasing load to obtain various points on a stress-strain diagram.

Q.53. Draw and explain stress-strain diagram for an elastic material.
(R.G.P.V., June 2015)

Or

Explain the stress-strain diagram for mild steel. (R.G.P.V., June 2014)

Or

Explain the stress-strain diagram of mild steel with the help of a neat sketch. (R.G.P.V., June 2013)

Or

Draw the stress-strain curve for mild steel. Also discuss the various properties of mild steel related to this curve. (R.G.P.V., June 2010)

Or

Draw stress-strain diagram for mild steel, clearly showing various points. (R.G.P.V., Dec. 2010)

Or

Explain stress-strain diagram for ductile materials. (R.G.P.V., March/April 2010)

Or

Discuss the stress-strain curve for a ductile material. (R.G.P.V., June 2012)

Or

Draw the stress-strain curve for a ductile metal and point out its salient features. (R.G.P.V., Dec. 2012)

Ans. Stress-strain Diagram for Ductile Materials – The tensile test for a ductile material is carried out with the help of a universal testing machine on the specimen made from the material to be tested. First of all, one end of the specimen is gripped in the jaws provided in the adjustable crosshead and then after lifting this crosshead to the height equal to length of the specimen. The other end of the specimen is fixed in jaws in the top crosshead. The tensile load is now applied to the specimen by turning the hand wheel. The load measuring gauge incorporated in the control unit shows the magnitude of the applied load. The load is gradually increased until the specimen breaks and the corresponding extensions are noted. The increase in length or elongation of the specimen depends upon the load applied. A graph is plotted with stresses along vertical axis and corresponding elongations along the horizontal axis. This graph is known as stress-strain diagram. Stress-strain diagram for ductile materials is shown in fig. 1.4.

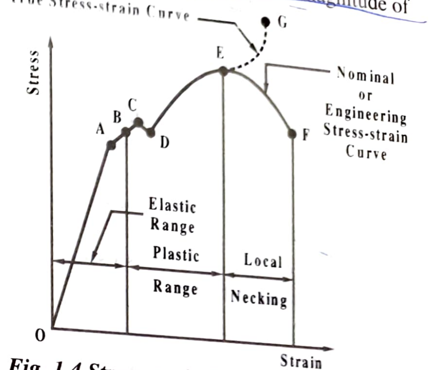


Fig. 1.4 Stress-strain Diagram for Mild Steel

Stress-strain diagram gives us information about the following important points –

(i) *Limit of Proportionality or Proportional Limit* – As the load is applied, the test piece tends to change or changes its dimensions, depending upon the magnitude of load. When the load is removed, the deformation disappears. This occurred upto a certain value of the strain. Within the elastic range, the limiting value of the stress upto which the stress and strain are proportional, is known as limit of proportionality. It is thus obvious that Hooke's law hold good upto limit of proportionality. We can see from the fig. 1.4 that from point O to A is a straight line which represents the stress is proportional to strain and the point A represents the limit of proportionality.

(ii) *Elastic Limit* – It may be observed that if the load is raised beyond point A upto the point B, the material will regain its shape and size when the load is removed. This means that the material has elastic properties upto the point B. The point B is called elastic limit. The elastic limit is defined as the stress developed in the material without any permanent deformation. In some materials, the proportional limit and the elastic limit are almost same, but in most of the materials, the elastic limit is higher than the proportional limit. At elastic limit, the deformation of different materials is different. In case of mild steel specimen, the deformation is about 2%.

(iii) Yield Point – When the load is increased beyond the elastic limit, plastic deformation will start, i.e., on the removal of the load, the material will not be able to recover its original shape and size. Simultaneously the specimen gets work hardened. A little consideration will show that beyond point B, the strain increases at a faster rate with any increase in the stress until the point C is reached. At the point C, the material yields before the load and there is appreciable strain without any increase in stress. For mild steel specimen, it will be seen that a small load drops to D, immediately after yielding commences. Hence for mild steel there are two yield points C and D. The points C and D are known as upper and lower yield points respectively. The highest value of stress after which a sudden extension occurs is known as the upper yield point, whereas the lower yield point is the stress which produces a considerable extension or elongation. The stress corresponding to yield point is known as yield point stress.

(iv) Proof Stress – Most ductile materials do not have a clear cut yield point. In this case, the curve passes smoothly from the elastic section to the section corresponding to plastic deformation. For such materials a proof stress at a specified strain is calculated. This is usually calculated upon completion of the test by an offset method. Although 0.2% is often employed for steels, and as much as 0.5% for cast iron.

(v) Ultimate Stress – At point D, the specimen regains some strength and higher values of stresses are needed for higher strains, than those between A and D. The stress goes on increasing till the point E is reached. The gradual increase in the strain of the specimen is followed with the uniform reduction of its cross-sectional area. The work done during stretching the specimen, is transformed largely into heat and the specimen becomes hot. At the point E, the stress, which attains its maximum value is known as ultimate tensile stress which is a measure of tensile strength of a material. Ultimate tensile stress is defined as the largest stress obtained by dividing the largest value of the load reached in a test to the original cross-sectional area of the test piece.

(vi) Breaking Stress – After the specimen has reached the ultimate tensile stress, a neck is formed, which decreases the cross-sectional area of the specimen. A little consideration will show that the stress necessary to break away the specimen, is less than the maximum stress. The stress is reduced until the specimen breaks away at point F. The stress corresponding to point F is called breaking stress.

Q.54. Sketch stress-strain diagram for M.S. and cast iron. Discuss various points for M.S. ***(R.G.P.V., June 2011)***

Or

Draw the stress-strain diagram for ductile and brittle material. ***(R.G.P.V., Dec. 2017)***

Ans. **Stress-strain Diagram for Mild Steel (Ductile Material)** – Refer Q.53.

Stress-strain Diagram for Cast Iron (Brittle Material) – The stress-strain diagram for a brittle material say cast iron is shown in fig. 1.5. Brittle materials are weak in tension due to the presence of sub-microscopic cracks which are oriented perpendicular to the axis of propagation of tensile stress.

Therefore, brittle materials like cast iron, stones, ceramics, mortars, bricks, etc. are tested in compression on a Universal testing machine. The specimen to be tested is placed between the compression plates, a strain gauge is attached to measure the compressive strain. The load or force is gradually applied on the specimen and the corresponding strain is recorded at regular intervals. Now with the recorded data, a graph is prepared with stresses along the vertical axis and the corresponding strains along the horizontal axis. The graph is known as stress-strain diagram.

Fig. 1.5 Stress-strain Diagram for Brittle Material

From fig. 1.5, we can see that there is a little strain as compared to the stress. There is always a point, where the specimen will fail due to shear along a diagonal plane. The value of breaking stress for different materials is different. But the general pattern for the stress-strain diagram is approximately the same as shown in fig. 1.5.

Q.55. Give classification of engineering materials. Give applications of cast iron and carbon steels. Plot stress-strain curve for cast iron. Distinguish between stress-strain curve and true stress-strain curve. (R.G.P.V., Dec. 2013)

Ans. **Classification of Engineering Materials** – Refer Q.2.

Applications of Cast Iron and Carbon Steels – Refer Q.6, Q.8, Q.9, Q.16, Q.17 and Q.18.

Stress-strain Curve for Cast Iron – Refer Q.54.

Difference between Stress-strain Curve and True Stress-strain Curve – In stress-strain curve of a ductile material, as shown in fig. 1.4, when stress reaches to its maximum value known as ultimate stress (as shown by point E), a neck starts to form which reduces the cross-section of the specimen, it causes the specimen to fail suddenly at F. If for each value of the strain between E and F, the tensile load is divided by the reduced cross-section area at the narrowest part of the neck, then the curve will follow the dotted line EG. This curve EG is called the ***true stress-strain curve***, while the curve EF is known as ***nominal*** or ***engineering stress-strain curve***.

NUMERICAL PROBLEMS

***Prob.1.** A rod 150 cm long and diameter 2 cm is subjected to an axial pull of 20 kN. If the modulus of elasticity of the material of the rod is 2×10^5 N/mm², determine stress, strain and the elongation of the rod.*

(R.G.P.V., June 2014)

Sol. Given, l = 150 cm = 1500 mm, d = 2 cm = 20 mm, P = 20 kN = 20×10^3 N, E = 2×10^5 N/mm²

Stress in the rod will be given by,

$$\sigma = \frac{\text{Axial pull}}{\text{Cross-sectional area}} = \frac{P}{\frac{\pi}{4}d^2}$$

$$= \frac{20 \times 10^3}{\frac{\pi}{4} \times (20)^2} = \mathbf{63.66\ N/mm^2} \qquad \textbf{Ans.}$$

Now modulus of elasticity for the rod,

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\varepsilon}$$

$$2 \times 10^5 = \frac{63.66}{\varepsilon}$$

$$\therefore \quad \varepsilon = \frac{63.66}{2 \times 10^5} = \mathbf{3.183 \times 10^{-4}} \qquad \textbf{Ans.}$$

Elongation of the rod will be given by,

$$\delta l = \varepsilon \times l$$

$$= 3.183 \times 10^{-4} \times 1500 = \mathbf{0.477\ mm} \qquad \textbf{Ans.}$$

HARDNESS AND IMPACT TESTING OF MATERIALS, BHN, ETC.

Q.56. Define hardness and explain the brinell hardness test.

(R.G.P.V., Dec. 2014)

Or

Define hardness. Explain any hardness testing method in brief.

(R.G.P.V., Dec. 2011)

Or

Define hardness and explain the testing procedure for determining hardness of engineering material. **(R.G.P.V., June 2012)**

***Ans.* Hardness** – Refer Q.38.

Brinell Hardness Test – The Brinell hardness test consists of pressing a hardened steel ball into a test specimen. The specimen is placed on the anvil, the handwheel is rotated so that the specimen along with the anvil moves up and contacts with the ball. The desired load is applied mechanically or hydraulically and the ball presses into the specimen. The diameter of the indentation made in the specimen by the pressed ball is measured by the use of a micrometer micro-scope, having a transparent engraved scale in the field of view. The diameter of indentation is measured at two places at right angles to each other and the average of the two readings is taken.

The Brinell hardness number (BHN) is the pressure per unit surface area of the indentation in kg per square metre.

$$BHN = \frac{W}{\left(\frac{\pi D}{2}\right)(D\sqrt{D^2 - d^2})}$$

where, W = Load on indenter, kg

D = Diameter of steel ball, mm

d = Average measured diameter of indentation, mm.

This test is best for measuring hardness of gray iron castings consisting of soft flake graphite, iron and hard iron carbide.

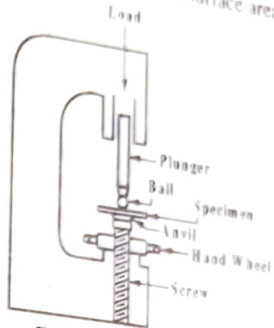


Fig. 1.6 Brinell Hardness Testing Machine

A Brinell hardness testing machine is shown in fig. 1.6.

Q.57. Write short note on – Hardness test. **(R.G.P.V., Dec. 2017)**

Ans. Refer Q.38 and Q.56.

Q.58. What do you mean by impact strength ?

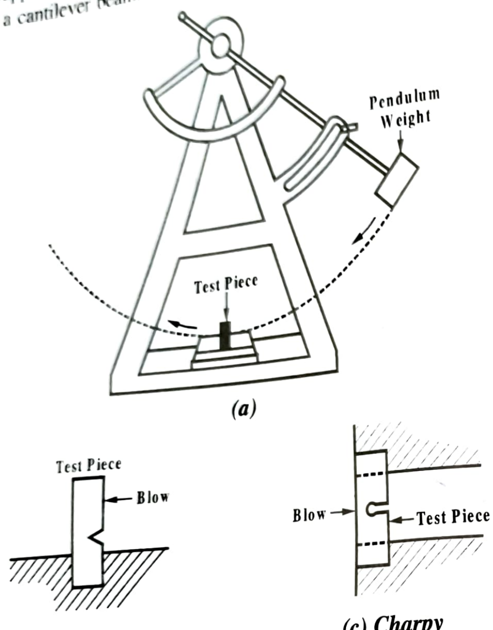
Ans. The capacity of a material to resist or absorb shock energy before its fracture is called its impact strength. It is a complex characteristic which takes into account both toughness and strength of a material. Impact strength for ductile materials is higher than that for brittle materials. Impact strength of a material can be determined by subjecting its specimen to impact loading under Izod or Charpy test. It is measured in cm-kg.

Q.59. What is impact testing ? Briefly explain the procedure of impact testing.

Ans. An impact test determines the behaviour of materials when subjected to high rates of loading, usually in bending, tension or torsion. In an impact test, a specimen, machined or surface ground and usually notched is struck and broken by a single blow in a specially designed testing machine. The quantity measured is the energy absorbed in breaking the specimen by a single

blow. An impact test gives an indication of the relative toughness of the material. The two types of specimen are used on impact testing machine, namely Charpy and Izod.

The Charpy specimen is placed in the vice in such a way that a simple beam supported at the ends whereas Izod specimen when placed in the vice acts as a cantilever beam.



(b) Izod (c) Charpy

Fig. 1.7 Impact Testing

Procedure – The swinging pendulum weight is raised to a height depending upon the type of specimen to be tested. With reference to the vice holding the specimen, the higher the pendulum, the more potential energy it has got. As the pendulum is released, its potential energy is converted into kinetic energy until it strikes the specimen.

The Charpy specimen is hit behind the V-notch while the Izod specimen is placed with the V-notch facing the pendulum. A part of the energy possessed by the pendulum is used to rupture the specimen and the pendulum rises on the other side of the machine to a height lower than its initial height on the opposite side of the impact testing machine. The energy absorbed in breaking the specimen is the weight of the pendulum times the difference in two heights of pendulum on either side of the machine. This energy is the notched impact strength and can be read from the dial of the impact testing machine.

Q.60. Write a short note on – Fatigue testing.

Ans. The fatigue test determines the stresses which a sample of material of standard dimensions can safely endure for a given number of cycles. This is accomplished using a specimen having a round cross-section, loaded at two points as a rotating simple beam and supported at its ends. The top surface of such a specimen is always in compression and the bottom surface is always in tension. The maximum stress always occurs at the surface, halfway along the length of the specimen, where the cross-section is minimum. For each complete rotation of the specimen, a point in the surface originally at the top centre goes alternately from a maximum in compression to a maximum in tension and then back to the same maximum in compression.

Specimens are tested to failure using different loads, and the number of cycles before failure is noted for each load. The results of such tests are plotted as graphs of applied stress against the logarithm of the number of cycles to failure. The curve is known as S-N curve. The usual procedure is to make a number of specimens of the same material and test them under different stress conditions.

Fig. 1.8 shows the two types of S-N curve.

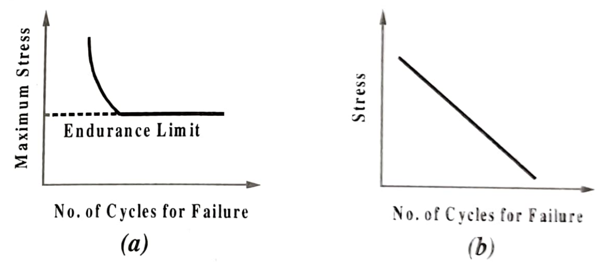


Fig. 1.8

Fig. 1.8 (a) shows a definite levelling off the curve, which indicates that the material has a definite fatigue limit. Commonly ferrous metals show distinct fatigue limit, while non-ferrous metals do not. The fatigue limit is about 40 to 60 percent of the tensile strength.

Q.61. How does a stress-strain curve of a brittle material differs from a ductile material ? Explain with the help of a plot. On which machine the tensile test of a material is performed ? What is the object of performing fatigue test on a material ? ***(R.G.P.V., Dec. 2013)***

Ans. **Difference between Stress-strain Curve of a Brittle Material and a Ductile Material** – Refer Q.54 and Q.53.

Tensile Test – Tensile test of a material is performed on a universal testing machine.

Object of Fatigue Test – The fatigue test is a dynamic type of test which determines the relative behaviour of materials when subjected to repeated or fluctuating loads. It determines the resistance of a metal to repeated or alternating loads, known as endurance strength of a material.

UNIT 2

MEASUREMENT AND PRODUCTION ENGINEERING

CONCEPT OF MEASUREMENTS, ERRORS IN MEASUREMENT

Q.1. Explain the term measurement. Give its significance.

Ans. In nature "whatever exists, exists in some amount". The determination of this amount is called measurement. The measurement of a given quantity is essentially an act or result, of a quantitative comparison between a predetermined standard and an unknown magnitude.

Broadly speaking there are two major functions of all branches of engineering –

(i) Design of equipments and processes.

(ii) Proper operation, control and maintenance of processes.

In the field of engineering design, research and development programme, the measurements and correct interpretation thereof are the source of great importance and necessary information.

In the process industries and power plants and other production industries, the aim is to achieve quality of product and have maximum efficiency. For this purpose and for the maintenance of operation, measurement plays a vital role.

The whole area of automation or automatic controls is based on measurements. In fact, the concept of control is based on the comparison of the actual condition (known by measurement) and the desired performance (set value).

Q.2. What are primary, secondary and tertiary measurements ? Explain with suitable examples.

Ans. **Primary Measurements –** A primary observation is one that can be made by direct observation without involving any conversion of the measured quantity. In this case, the change in the measured quantity stimulates a set of the observer's nerve endings, so that the observer can see or sense the change directly. Examples of primary measurement are (i) the matching of two lengths, such as when determining the length of an object with a metre rod, (ii) the matching of two colours, such as when judging the colour of red hot metals.

For example, a typical laboratory standard used for calibration is approximate. Accordingly, there may be a difference between the value of the standard used and the value of the primary standard that it represents. Hence, there is an uncertainty in the input value on which calibration is based. Further, there can be a difference between the value supplied by the standard and the calibration value actually sensed by the measuring system. A list of common elemental errors contributing to calibration errors is given in table 2.1.

Table 2.1

Element (j)	*Error Source*
1	Primary to interlab standard
2	Interlab to transfer standard
3	Transfer to lab standard
4	Lab standard to measurement system
5	Calibration technique

***(ii) Data Acquisition Errors* –** All errors that arise during the actual act of measurement are referred to as data acquisition errors. These errors include sensor and instrument errors, uncontrolled variables, such as changes or unknowns in measurement system operating conditions, power settings and environmental conditions that affect system performance and sensor installation effects on the measurand. In addition, the measured variable temporal and spatial variations contribute data acquisition errors. A list of common elemental errors contributing to data acquisition errors is given in table 2.2.

Table 2.2

Element (j)	*Error Source*
1	Measurement system operating conditions
2	Sensor-transducer stage (instrument error)
3	Signal conditioning stage (instrument error)
4	Output stage (instrument error)
5	Process operating conditions
6	Sensor installation effects
7	Environmental effects
8	Spatial variation error
9	Temporal variation error

***(iii) Data Reduction Errors* –** The use of curve fits and correlations technique with their associate unknown introduces data reduction errors into the reported test results. The resolution of computational operations required to reduce the data into some desired result is another common contribution to data reduction errors.

Q.7. Discuss the various types of errors in measurement.

(R.G.P.V., Dec. 2017)

Ans. The various types of errors occur during measurement may be grouped into following three categories –

***(i) Gross Errors* –** Gross errors occur because of mistakes in reading or using instruments and in recording and calculating measurement results. These errors are usually because of human mistakes and these may be of any magnitude and cannot be subjected to mathematical treatment.

One common gross error frequently committed during measurement is improper use of the measuring instrument. Any indicating instrument changes conditions to some extent when connected into a complete circuit so that the reading of measurand quantity is altered by the method used. Gross errors are also contributed by the other factors such as improper reading of an instrument, failure to eliminate parallax or recording the result different from the actual reading taken or adjusting the instrument incorrectly. These errors cannot be treated mathematically so a great care should be taken during reading and recording the data to avoid these errors.

***(ii) Systematic Errors* –** These errors remain constant or change according to a definite law on repeated measurement of the given quantity. These errors can be evaluated and their influence on the results of measurement can be eliminated by the introduction of proper corrections.

Systematic errors are of two types namely instrumental errors and environmental errors.

Instrumental errors are inherent in the measuring instruments because of their mechanical structure and calibration or operation of the apparatus used. These errors may be detected by checking for erratic behaviour, stability and reproducibility of results. A quick and easy way to check an instrument is to compare it with another instrument of same characteristics or compare it with a comparatively more accurate instrument. Such errors may be avoided by selecting a proper measuring device for the particular application.

Environmental errors are much more troublesome as these change with time in an unpredictable manner. These errors are introduced due to using an instrument in different conditions than in which it was assembled and calibrated. Change in temperature is the major cause of such errors as temperature affects the properties of materials in many ways, including dimensions, resistivity, spring effect and other. These errors can be eliminated or reduced by using instrument in controlled conditions of pressure, temperature and humidity in which it was originally assembled and calibrated.

***(iii) Random Errors* –** These errors are of variable magnitude and sign and do not obey any known law. The presence of random errors becomes

evident when different results are obtained on repeated measurements of one and the same quantity. The effect of random errors is minimized by measuring the given quantity many times under the same conditions and calculating the arithmetical mean of the values obtained.

Q.8. Explain the following properties of any measuring instrument –
(i) Hysteresis (ii) Sensitivity
(iii) Accuracy and precision (iv) Errors
(v) Response time. ***(R.G.P.V., June 2011)***

Ans. (i) Hysteresis – Hysteresis is a phenomenon which depicts different output effects with loading and unloading whether it is a mechanical system or an electrical system or any other system. Hysteresis is thus, non-coincidence of loading and unloading curves. Hysteresis, in a system, arises due to the fact that all the energy which put into the stressed parts during loading is not recoverable upon unloading. This is because of the second law of thermo dynamics according to which there is no perfect reversible process in this universe.

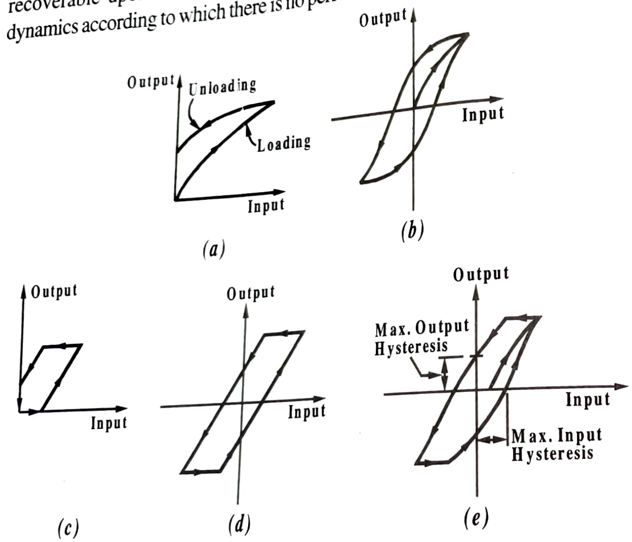


Fig. 2.1 Hysteresis Effects

In an instrument which has no friction due to sliding of parts, the output varies as shown in fig. 2.1 (a) when input is slowly varied from zero to full scale and then back to zero. The non-coincidence of output when the input is increased and then decreased is on account of internal friction or hysteretic damping. In case of instruments which are used on both sides of zero i.e., input applied on both positive and negative sides, the variation of output is as shown in fig. 2.1 (b).

In case of instruments, which do not have internal friction, but have external sliding friction, i.e., constant Coulomb friction, the input-output relationships are like the ones shown in fig. 2.1 (c) and (d). In an instrument a number of causes such as listed above combinely give an overall effect which may result in output-input relationship such as shown in fig. 2.1 (e). The numerical value of hysteresis can be specified in terms of either output or input and is usually given as a percentage of full scale.

(ii) Sensitivity – Sensitivity is the ratio of the magnitude of output to the input signal or the response of measuring system to the quantity being measured. Its units are millimetre per micro-ampere, counts per volt etc. depending upon the type of input and output.

For an instrument having linear calibration curve sensitivity is the slope of the calibration curve and is constant over the entire range of the instrument. If the calibration curve is non-linear, the sensitivity will be different at different points, being the slope of curve at various points. The sensitivity of an instrument should be high and thus the range should not be high in comparison to value being measured.

(iii) Accuracy and Precision – Accuracy is defined as the closeness with which an instrument reading approaches the true value of the quantity being measured. Thus accuracy of a measurement means conformity to truth. True value of a quantity can be defined as the average of an infinite number of measured values when the average deviation due to the various contributing factors tends to zero. Any measurement system does not indicate true value because of loading effects, lags, mechanical problems like wear, hysteresis, noise pick up, etc. Some inaccuracy thus has to be accepted in measurements.

The accuracy may be specified in terms of inaccuracy or limits of error and can be expressed as point accuracy or as percentage of scale range, or as percentage of true value.

In general usage, the distinction between accuracy and precision is usually very vague. But in the field of measurement there is a sharp difference between the two terms.

Precision of an instrument is the extent at which the instrument repeat its result when making repeat measurements on the same unit of product. The term precise means clearly or sharply defined. If an instrument is not precise, it will give different results for same value when measured again and again. Such an instrument thus is considered non-trust worthy. The first and fundamental requirement of any good instrument to be effective is that it should have adequate precision.

(iv) Errors – Refer Q.4.

(v) Response Time – All measuring instruments consist one or more energy storage elements. These energy storage elements include electrical inductance and capacitance, mass and inertia and thermal and fluid capacitance. When an input is applied to a measuring system, these energy storage elements

do not allow an immediate flow of energy and therefore the measurement system does not respond to the input immediately. This time delay is called response time of a measuring instrument.

Response time is defined as the time taken by an instrument to show 63.2% change in reading to a step input.

Q.9. Define the following measurement terms –

(i) Accuracy *(ii) Sensitivity*
(iii) Precision *(iv) Hysteresis*
(v) Error.

(R.G.P.V., Dec. 2010)

Ans. (i) Accuracy – Refer Q.8. section (iii).

(ii) Sensitivity – Refer Q.8. section (ii).

(iii) Precision – Refer Q.8. section (iii).

(iv) Hysteresis – Refer Q.8. section (i).

(v) Error – Refer Q.4.

Q.10. Explain the term threshold value of any measuring instrument.
(R.G.P.V., June 2015)

Ans. It has been found if the instrument output is increased very gradually from zero there will be some minimum value below which no output change can be detected. This minimum value is defined as threshold of the instrument. In specifying threshold, the first detectible output change is often described as being any "noticeable measurable change".

This phenomenon is due to input hysteresis.

Q.11. Distinguish between –

(i) Range and span
(ii) Error and accuracy
(iii) Accuracy and precision.

(R.G.P.V., Dec. 2015)

Ans. (i) Range and Span – The range of the instrument is specified by the lower and upper limits in which it is designed to operate for measuring, indicating or recording the measured variable. It has a very important bearing on the expected accuracy of the instrument. The range of the instrument is so selected that for the working parameter, the pointer deflection is about 2/3rd of the scale. The range of the instrument can either be unidirectional (e.g. 0 to 100°C) or bidirectional (e.g. – 10 to 100°C).

The algebraic difference between the upper and lower range values is termed as the span of the instrument.

(ii) Error and Accuracy – Error is defined as the difference between the measured and the true value (as per standards).

On the other hand accuracy of a measuring system is defined as the closeness of the instrument output to the true value of the measured quantity (as per standards). In actual practice, accuracy is specified as the percentage deviation or inaccuracy of the measurement from the true value. Accuracy of an instrument depends on various systematic errors involved in the measurement process. For example, the accuracy of a common laboratory micrometer depends on instrument errors like zero error, errors in the pitch of screw, and measurement process errors caused due to temperature variation effect, applied torque, etc.

(iii) Accuracy and Precision – Refer Q.8. section (iii).

TEMPERATURE AND PRESSURE MEASUREMENT

Q.12. Define temperature and name one device and its operating principle for measuring temperature. ***(R.G.P.V., Dec. 2014)***

Ans. Temperature can be defined as the degree of hotness or coldness of a body. Temperature can also be defined as condition of a body by virtue of which heat is transferred to or from the bodies.

One of the most commonly used device for temperature measurement in industries is a thermocouple. A thermocouple works on the seeback effect, viz. if two wires of different metals are joined together at each end to form a complete electric circuit, then current flows in the circuit when two junctions are kept at different temperatures.

Q.13. Classify the temperature measurement instruments.
(R.G.P.V., Dec. 2016)

Ans. Temperture measurement instruments can be classified into following two groups –

(i) Contact type (ii) Radiation type.

(i) Contact Type – In contact type temperature measuring instruments, the indicator is placed in direct contact with the heat source. Resistance thermometers, thermistors, thermocouples, bimetallic thermometers, thermopiles and semiconductor thermometers fall in this category.

(ii) Radiation Type – In this group of temperature measuring instruments the instruments operate either on total radiation, i.e., heat and light from the hot body, or on the visible radiation. The instruments operating on total radiation from the hot body are called the radiation type instruments while those operating on visible radiation are called the optical type instruments. These temperature measuring instruments are particularly suitable for the measurement of very high temperatures, the upper limit of their range being fixed mainly by difficulties of calibration. Radiation pyrometers and optical pyrometers fall in this class.

Q.14. Write down the principle of temperature measurement.
(R.G.P.V., June 2015)

Or

Explain the principle of temperature measurement.
(R.G.P.V., Jan./Feb. 2008, June 2014)

Ans. The international measuring system sets up independent standards for only four quantities – length, time, mass and temperature. Out of these, the temperature phenomenon is different from the rest of three. For example, if two bodies of like length are joined, the total length is twice the original; the same is true for two time intervals or two masses. However, the combination of two bodies of the same temperature results in exactly the same temperature. Thus, the idea of a standard unit of mass, length or time that can be divided or multiplied indefinitely to generate any arbitrary magnitude of these quantities cannot be carried over to the concept of temperature.

According to Zeroth law of thermodynamics, "when two bodies are each in thermal equilibrium with a third body, then they are said to be in thermal equilibrium with each other". Then, by definition, the bodies are all at the same temperature. Thus, if we can set up a reproducible means of establishing a range of temperatures, unknown temperatures of other bodies may be compared with the standard by subjecting any type of thermometer successively to the standard and to the unknown temperatures and allowing equilibrium to occur in each case.

A standard temperature scale can be defined by employing any of the many physical properties of materials that vary reproducibly with temperature. However, a standard based on a particular substance cannot give accurate result for other substances. To overcome this difficulty, a temperature scale independent of any substance is desirable.

The thermodynamic temperature scale as suggested by Lord Kelvin in 1848, independent of any material property can be considered as standard temperature scale. On this scale, the fixed point is taken as the triple point of water because this is the most reproducible state known. The number assigned to this point is 273.16 K. Since this makes the temperature interval from the ice point (273.15 K) to the steam point equal to 100 K.

Q.15. Describe with a neat sketch, the working of a bimetallic thermometer. ***(R.G.P.V., Dec. 2015)***

Ans. Bimetallic thermometer employs the principle of solid expansion and consists of a bimetal strip usually in the form of a cantilever beam. This comprises strips of two metals, having different coefficients of thermal expansion, welded or riveted together so that relative motion between them is prevented. An increase in temperature causes the deflection of the free end of the strip.

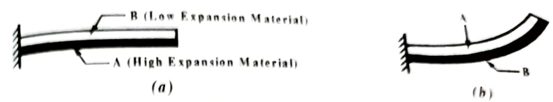


Fig. 2.2 Bimetal Strip

The deflection with the temperature is nearly linear, depending mainly on the coefficient of linear thermal expansion. Invar is commonly employed as the low expansion metal. This is an iron-nickel alloy containing 36% nickel. Its coefficient of thermal expansion is around 1/20th of the ordinary metals. Brass is used as high expansion material for the measurement of low temperatures whereas nickel alloys are used when higher temperatures have to be measured. A bimetallic strip is somewhat insensitive, but the sensitivity is improved by using a longer strip in a helical form as shown in fig. 2.2 (c).

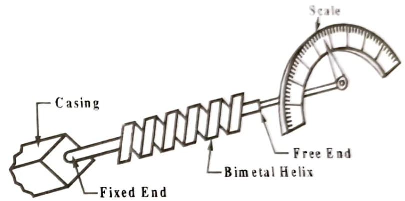


Fig. 2.2 (c) Bimetal Helix Thermometer

One end of the helix is anchored to the casing and the other end which is free is conveniently connected to the pointer which sweeps over circular dial graduated in degrees of temperature. In response to temperature change, the bimetal expands and the helical bimetal rotates at its free end, thus turning the stem and the pointer to a new position on the dial. The length of the stem may be upto about 0.6 m, allowing the bimetal element to be submerged in a hot substance without the indicator itself being subjected to excessive temperatures. Bimetallic thermometers are used in the – 30ºC to 550ºC range.

Q.16. Explain the construction and working of a thermocouple.

Ans. Thermocouples are the most simple and most widely used devices for temperature measurement. It essentially consists of two dissimilar metal wires, insulated from each other but welded or brazed together at their ends forming two junctions. The operation of a thermocouple is based on Seebeck effect i.e., if two wires of different metals are join together at each end and form a complete electric circuit then current flows in the circuit when two junctions are kept at different temperatures. This current is caused by an e.m.f., called the thermo-electric effect set up in the circuit and is a function of the temperature difference of the two junctions (the hot junction, whose temperature is to be measured and the cold or reference junction which is maintained at a constant temperature).

If T_1 and T_2 be the temperatures of the two junctions, and an infinite resistance voltmeter is connected between the wires, it will detect the e.m.f. E, or if a low resistance ammeter is connected, the current flow, I can be measured. For standardization one of the two junctions is usually maintained at some known temperature (commonly ice point). The measured e.m.f., E then indicates the temperature difference relative to the reference temperature.

Construction – A thermocouple can be formed by joining the two dissimilar metals at their ends forming two junctions, called the thermojunctions. The two metals can be joined either by welding or by soldering. Welding is done without using any flux and is commonly used for platinum-rhodium and chromel-alumel. For the other types besides flux less welding, silver soldering may be done. Two wires of thermocouple are insulated from each other by a material which can withstand the highest temperature to which the thermocouple is to be exposed. Usually, the thermocouple wires are entirely covered by a sheath and the free ends of the thermocouple wires are terminated on terminals suitably shaped for making connections to the compensating leads. The terminals are arranged in a head which is attached to the protecting sheath.

Q.17. Name various pressure measurement devices.

Ans. The various devices used for pressure measurement are of two types, manometers and mechanical gauges. Their further subdivisions are as follows –

(i) ***Manometers*** – Piezometer tube, single column manometer, U-tube differential manometer, inverted U-tube differential manometer micro-manometer, inclined manometer.

(ii) ***Mechanical Gauges*** – Pressure gauge, vacuum gauge, compound gauge.

In addition to above mentioned devices, pressure transducers and electronic pressure cells such as piezo-electric cells are used for pressure measurement.

Q.18. Explain the working of a Bourdon pressure gauge with neat sketch. ***(R.G.P.V., Jan./Feb. 2008)***

Ans. A Bourdon pressure gauge is commonly used for measuring pressure. This incorporates an elastic Bourdon tube. The cross-section of the tube, due to pressure, tends to round out. The tube uncoils since the inner and outer arc lengths remain almost equal to their original lengths. The motion of the end of the tube is amplified and indicated by a pointer moving on a calibrated scale.

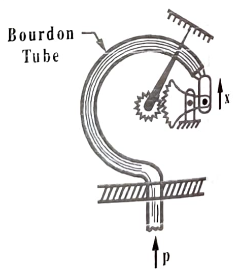


Fig 2.3 Bourdon Pressure Gauge

Usually, an electromechanical transducer is used along with the elastic element, especially when dynamic pressures are to be measured. The output voltage can be indicated or recorded by a suitable instrument like an oscilloscope or a recorder.

Q.19. What is a U-tube manometer ?

Ans. A manometer is the simplest device for measuring static pressure. A simple U-tube manometer as shown in fig. 2.4 uses water, mercury or any other suitable fluid. The difference in levels (h) between the two limbs is an indication of the pressure difference $(p_1 - p_2)$ between the two limbs. If one of the pressures, say that applied to limb2, is atmospheric, the difference gives the gauge pressure applied to limb1

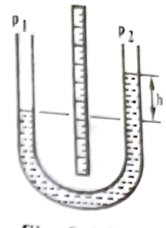


Fig. 2.4 U-tube Manometer

$$h = (p_1 - p_2)\rho g$$

where, ρ = Mass density of the liquid used in the manometer.

Q.20. Explain pressure measurement by pressure transducers and piezo-electric cells.

Ans. A pressure transducer is used to measure absolute pressure and its variation by measuring some electrical quantity.

A pressure transducer usually has a thin diaphragm, on one side of which the fluid pressure acts. The movements of the diaphragm caused by the change of pressure are indicated by an electrical strain gauge on the diaphragm which with proper calibration would facilitate the measurement of pressure. Alternatively the change of electrical capacitance between the moving diaphragm and a fixed plate may be measured which would also facilitate the measurement of pressure. Most of the pressure transducers will respond to very high pressure and to fluctuations of pressure of several cycles/sec.

Piezo-electric cells are electronic pressure cells suitable for measuring very high pressures as well as pressure fluctuations. These devices use a crystal of quartz or other material which when subjected to the pressure of fluid, produces across itself a small but measurable difference of electrical potential. The quartz crystal will respond to pressure as great as 350 kg/cm^2 and to fluctuations of pressure from 1 to 10000 cycles/sec. Some pressure gauges utilize the increase of electrical resistance exhibited by metals under very high pressures.

Q.21. Briefly explain the devices used for measuring the pressure of a fluid. ***(R.G.P.V., June 2014)***

Or

Explain the various pressure measurement instruments. ***(R.G.P.V., June 2010)***

Ans. Refer Q.18, Q.19 and Q.20.

VELOCITY AND FLOW MEASUREMENT

Q.22. Discuss in brief velocity measurement.

Ans. For the measurement of velocity at different points in the flow field, the following devices are commonly adopted –

(i) Pitot tube (ii) Current meter (iii) Hot-wire anemometer.

The mean velocity of flow may be determined by integrating the velocity distribution profile over the entire section of the flow passage. Often an indirect method is used for determining the mean velocity of flow which involves the measurement of the discharge and the area of the flow passage.

Linear velocity is measured by converting linear motion into an angular motion when distance travelled is long.

The measurement of angular velocity is more prominent than that of linear velocity. The various devices used in measurement of angular velocity are eddy current tachometer, D.C. generator tachometer, A.C. generator tachometer, drag cup rotor A.C. generator tachometer, toothed rotor or variable reluctance tachometer and photo electric pickup tachometer.

Q.23. Name various transducers used for measurement of linear velocity. Discuss working principle of electromagnetic transducers.

Ans. Velocity is the first derivative of displacement. The methods used for measurement of linear velocity utilize the following types of transducers –

(i) Electromagnetic transducers
(ii) Seismic type transducers
(iii) Digital transducers
(iv) Transducers utilizing the Doppler effect.

Electromagnetic Transducer – A electromagnetic transducer utilizes the voltage produced in a coil on account of change in flux linkages resulting from change in reluctance.

In general, the output voltage from a coil is given by,

$$e_0 = \frac{d\phi}{dt}$$

where, $\phi = \text{Flux} = \frac{\text{mmf}}{\text{Reluctance}} = \frac{Ni}{R}$

$$\therefore \quad e_0 = N\frac{d}{dt}\left(\frac{i}{R}\right)$$

$$= \frac{N}{R}\cdot\frac{di}{dt} - \frac{Ni}{R^2}\frac{dR}{dt}$$

If current i is asssumed to be constant, then

$$e_0 = -\frac{Ni}{R^2}\cdot\frac{dR}{dt}$$

or

$$e_0 \propto \frac{dR}{dt}$$

Derivation of above equation is based upon the following assumptions –

(i) The average value of R is considerably greater than the variations in R.

(ii) Quantity $\frac{Ni}{R^2}$ is approximately constant.

In this type of transducer reluctance of iron parts is assumed to be negligible and reluctance of magnetic path is only due to the reluctance of air gap. The reluctance therefore varies directly with the length of air gap and output voltage is directly proportional to rate of change of length of air gap and hence to the linear velocity. Thus this type of transducer is velocity sensitive.

The electromagnetic transducers may be of the following two types –

(i) Moving magnet type (ii) Moving coil type.

Q.24. Write short note on – Flow measurement.

Ans. Flow is the most important variable in any plant operation. The measurement of flow is very important in many industrial applications such as transportation of solids as slurries, compressed natural gas in pipelines, water and gas supply to domestic consumers, irrigation systems, etc.

Many accurate and reliable methods are available for the measurement of flow. Choice of a particular method depends upon the material and its condition, the type of flow, the volume, the range and rangeability, the pressure and temperature change, the accuracy needed and the control required.

The nature of fluid whose flow is to be measured may be of different types. For example, fluids may be clear or opaque, clean or dirty, wet or dry, erosive or corrosive. Fluid streams may be multiphase, vapour, liquid or slurries. The flow may be laminar or turbulent. Pressure may vary from near vacuum to many times atmospheres, and temperatures may vary from cryogenic to hundreds of degrees of Celsius. Flow requirement may vary from a few drops per hour to thousands of litres per minute.

Thus, selection of the best method for a particular application depends upon the given set of conditions as discussed above.

Q.25. How will you measure flow ? Name instruments used.
(R.G.P.V., June 2016)

Ans. Flow measurement is concerned either with flow rate or total flow. On this basis, there can be two types of flow meters –

(i) Rate flow meters (ii) Quantity meters.

The rate flow meters either measure the volumetric flow rate directly or measure velocity of flow which can be multiplied with area of cross-section to obtain the flow rate.

Quantity meters measure the total flow or the amount of fluid that flows across a given point in a specified interval of time. The average flow rate can be obtained by dividing the quantity of fluid flow by the time taken to flow.

Some commonly used instruments for flow measurement include –

(i) Variable area or rotameter (ii) Swirl meters
(iii) Venturimeter (iv) Orifice meter
(v) Nozzle meter (vi) Pitot tube.

Q.26. Explain the principle of operation of rotameter for discharge measurement. ***(R.G.P.V., Dec. 2015)***

Ans. A rotameter is a constant pressure drop, variable area flow meter. It is called as variable area flow meter because, it consists of an upright tapered glass tube with its narrow end down and larger end up as shown in fig. 2.5. The glass tube consists of a float which is free to move within the tube. The float is made of such a diameter that it completely blocks the inlet of tube. The fluid flows through the tube from bottom to the top.

When no fluid is flowing, the float rests at the bottom of the tube when the flow starts in the pipe line and the fluid reaches the float, the buoyant effect of fluid tries to lift the float. But the float is made of such a material that its density is greater than that of the flowing material, so that the buoyant effect alone is not sufficient to lift the float. The float passage remains closed until the pressure of the flowing material plus the fluid buoyancy effect, exceeds the downward pressure due to the weight of the float. The float then rises and floats within the flowing medium in proportion to the flow at the given pressure. As the float moves upward, an annular passage is formed between the inner wall of the glass tube and periphery of float. This forms a concentric opening through which the flowing material passes. The float continues to rise until a condition of equilibrium is reached where the upward thrust on the float, due to the differential pressure generated by the metered fluid passing through the annular passage formed, balances the downward thrust of the float due to its weight.

Now any increase or decrease in flow rate will cause the float to rise higher or sink lower respectively. Thus, every float position corresponds to one particular flow rate. The float gives a reading on a calibrated scale etched on the glass tube, from which flow rate can be determined.

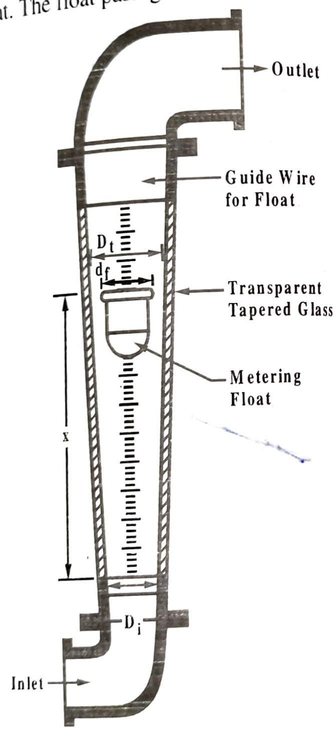


Fig. 2.5 Rotameter

Advantages –

(i) In rotameter, volume flow rate is linearly proportional to the displacement of the float from its zero position. Hence, the scale of rotameters is linear, unlike in the case of variable head meters.

(ii) Rotameters have a pressure drop that is essentially constant over the entire range. Thus, only one correction needs to be made over the entire range of meter.

(iii) They can be used for liquids, gases and vapours.

(iv) They are not affected by the viscosity of the fluids.

(v) They can be used for measurement of low flow rates.

(vi) Their accuracies range from ±0.5% to 10%

Disadvantages –

(i) They must be mounted vertically as the gravity vector affects the flow rate. Vertical accelerations affect the value of g. These two factors limit the use of rotameters. For example, they cannot be used for measurement in moving objects.

(ii) The vertical glass tube is subjected to static pressure and any surge pressure in the system. Therefore, it is likely to break when pressure exceeds a particular value.

(iii) Maximum size of a pipe diameter is limited by cost, weight and handling problems.

Q.27. Explain the principle of venturimeter with a neat sketch and derive the expression for the rate of flow of fluid through it. ***(R.G.P.V., June 2014)***

Or

What is venturimeter ? Derive the expression for measuring rate of flow of fluid in a horizontal pipe. ***(R.G.P.V., Dec. 2014)***

Or

Describe the measurement of flow rate of a fluid flowing through a circular pipe. ***(R.G.P.V., June 2012)***

Ans. A venturimeter is a device which is used for measuring the rate of flow of fluid through a pipe. It works on the principle that by reducing the cross-sectional area of the flow passage a pressure difference can be created, and by measuring this pressure difference, discharge through the pipe can be determined.

A venturimeter as shown in fig. 2.6 consists of following three parts –

(i) A short converging cone
(ii) Throat
(iii) A long diverging cone.

The inlet of the venturimeter is of same diameter as that of a pipe which is followed by a convergent cone. Convergent cone is a short pipe which tapers from inlet pipe diameter to throat diameter. The throat is a cylindrical pipe of cross-section area smaller than that of pipe. The divergent cone is long pipe which tapers gradually from throat diameter to outlet pipe diameter.

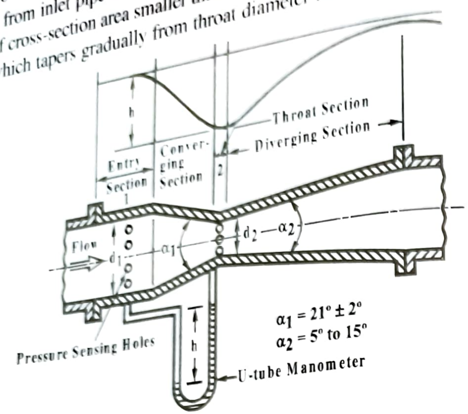


Fig. 2.6 Venturimeter

As cross-sectional area of throat is smaller than that of the inlet pipe, thus velocity of flow get increased as per the continuity equation. This increase in velocity of flow reduces the pressure at the throat of the venturimeter. By measuring this pressure difference with the help of a differential manometer rate of flow of fluid, i.e. discharge can be measured.

Consider a venturimeter fitted in a horizontal pipe through which a fluid (say water) is flowing, as shown in fig. 2.6. Consider two sections 1 and 2 at the inlet and throat of the venturimeter respectively.

Let, p_1 = Pressure at section 1

v_1 = Velocity of flow at section 1

a_1 = Cross-sectional area of pipe at section 1 = $\frac{\pi}{4} d_1^2$

d_1 = Diameter of pipe of section 1

p_2, v_2, a_2 and d_2 = Corresponding values at section 2.

Applying Bernoulli's equation at sections 1 and 2, we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

As pipe is horizontal, hence $z_1 = z_2$

$$\therefore \quad \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g}$$

or
$$\frac{p_1 - p_2}{\rho g} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \quad ....(i)$$

where $\frac{p_1 - p_2}{\rho g}$ is the pressure head difference at sections 1 and 2 and it is equal to h.

Substituting this value of $\frac{p_1 - p_2}{\rho g}$ in equation (i), we get

$$h = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \quad ....(ii)$$

Now, applying continuity equation at sections 1 and 2

$$a_1 v_1 = a_2 v_2 \text{ or } v_1 = \frac{a_2 v_2}{a_1}$$

Substituting this value of v_1 in equation (ii)

$$h = \frac{v_2^2}{2g} - \frac{\left(\frac{a_2 v_2}{a_1}\right)^2}{2g} = \frac{v_2^2}{2g}\left[1 - \frac{a_2^2}{a_1^2}\right] = \frac{v_2^2}{2g}\left[\frac{a_1^2 - a_2^2}{a_1^2}\right]$$

or
$$v_2^2 = 2gh \frac{a_1^2}{a_1^2 - a_2^2}$$

$$\therefore \quad v_2 = \sqrt{2gh \frac{a_1^2}{a_1^2 - a_2^2}} = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

$\therefore$ Discharge,

$$Q = a_2 v_2 = a_2 \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} \quad ....(iii)$$

Equation (iii) gives the theoretical discharge under ideal conditions, actual discharge can be given by

$$Q_{act} = C_d \frac{a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}} \quad ...(iv)$$

Here C_d = Coefficient of discharge of venturimeter, which is defined as the ratio of actual discharge to the theoretical discharge = $\frac{Q_{act}}{Q_{th}}$.

Q.28. What is orifice meter ? Draw its diagram and give the formula used for measurement. ***(R.G.P.V., Dec. 2014)***

Ans. An orifice meter is used for measuring the discharge of flow. It works on the same principle as that of a venturimeter, i.e. by reducing the

cross-sectional area of flow passage a pressure difference can be created, by measurement of which discharge through the pipe can be obtained.

An orifice meter as shown in fig. 2.7, consists of a flat circular plate which has a sharp edged hole called orifice, which is concentric with the pipe. Orifice diameter varies from 0.2 to 0.85 times the pipe diameter.

Flow through the orifice is measured by using formula

$$Q = \frac{C_d a_0 a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$$

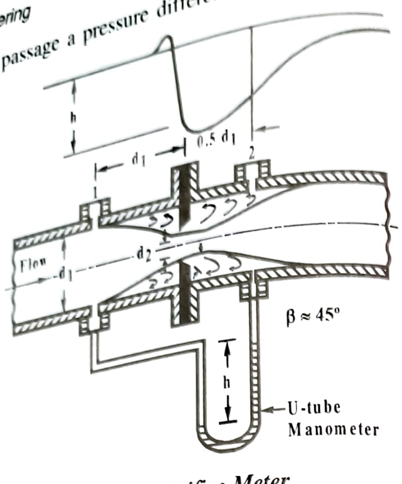


Fig. 2.7 Orifice Meter

STRAIN, FORCE AND TORQUE MEASUREMENT

Q.29. What do you mean by strain measurement ?

Ans. When a material is subjected to a load, it gets deformed and a strain is produced. By measuring this strain, force or torque which produce this strain can be estimated.

Strain is measured with the help of strain gauges. Resistance of strain gauges gets changed under strained condition and since this change in resistance is very small, of the order of 0.2% so for its measurement extremely sensitive and sophisticated instrumentation is required. Strain gauges employ circuits using potentiometer or wheatstone bridge networks.

Q.30. Write short note on mechanical strain gauges.

Ans. Mechanical strain gauges employ a mechanical means for magnification. Earlier an extensometer of single mechanical lever type having a magnification of 10:1 was used. This used to work on a long gauge length. Now-a-days, extensometers employing compound levers (dial gauges), having a magnification of 2000:1 are in use. They are capable to operate over small gauge lengths. The most commonly used mechanical strain gauges are of Berry type and Huggen berger type.

The advantage of mechanical strain gauge is that it has self-contained magnification system and no auxiliary equipment is needed as in case of electrical strain gauges. However, they are only suited for static tests. The high inertia of

gauges makes them unsuitable for dynamic measurements and varying strains, also there is no method of automatically recording the readings. Further, there should be sufficient surface area on the test specimen and clearance above it in order to accommodate the gauge together with its mounting fixture.

Q.31. Discuss the principle and working of resistance strain gauge.

Ans. A resistance strain gauge is a passive transducer which converts a mechanical displacement into a change of resistance. A strain gauge is a thin, wafer-like device which can be attached to a variety of materials for the measurement of applied strain. Metallic strain gauges are formed from small-diameter resistance wire, like constantan, or etched from the thin foil sheets. Resistance of the wire or metal foil changes with length as the material to which the gauge is attached undergoes tension or compression. This change in resistance, which is proportional to the applied strain, is measured with a specially adopted wheatstone bridge.

Working of resistance strain gauge is based on the principle that when a stress is applied on the metal conductor its length increases, while its area of cross-section decreases as shown in fig. 2.8. Since the resistance of a conductor is proportional to its length and inversely proportional to its area of cross-section, the resistance of the gauge therefore increases with positive strain.

Resistance of the conductor under stress is also changed due to change in resistivity of the conductor, this property is referred to as the piezo-resistive effect. This is the reason, why strain gauges are also known as the piezo-resistive strain gauges.

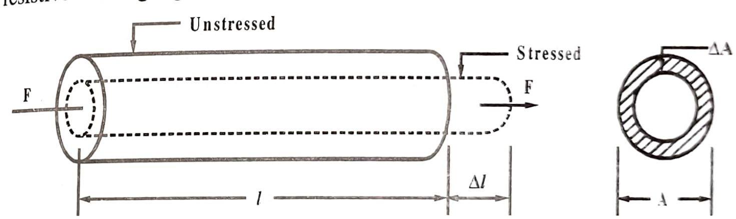


Fig. 2.8

The most important parameter of the strain gauges is the gauge factor, which is a measure of the amount of resistance change for a given strain and is thus an index of the strain sensitivity of the gauge. The gauge factor is defined as the ratio of per unit change in resistance to per unit change in length, i.e. gauge factor.

$$G_f = \frac{\Delta R/R}{\Delta L/L}$$

Q.32. What is the use of Brittle lacquer method ? (R.G.P.V., Dec. 2016)

Ans. In brittle lacquer method, a special lacquer coating that cracks when exposed to certain strain levels is sprayed onto the object whose stress behaviour

is need to be determined. Coating when reaches its fracture threshold, a pattern of cracks appear on the surface. The coating cracks normal to the direction of principal strain, thereby defining the directions of the principal stresses in the specimen or model.

Thus, this method is mainly used to identify the principal strain orientations, which helps to orient the strain gauge on the part. Knowing critical stress level of the coating also allows estimation of the magnitude of the maximum principal stress. This also helps to predict fatigue life of the component. This method can be used on any surface of the structure, regardless of material, shape or type of loading.

Q.33. Enlist various methods of force measurement.

Ans. An unknown force may be measured by the following means –

(i) Balancing it against the known gravitational force on a standard mass, either directly or through a system of levers.

(ii) Balancing it against a magnetic force developed by interaction of a current carrying coil and a magnet.

(iii) Measuring the acceleration of a body of known mass to which the unknown force is applied.

(iv) Transducing the force to a fluid pressure and then measuring the pressure.

(v) Applying the force to some elastic member and measuring the resulting deflection.

(vi) Measuring the change in precession of a gyroscope caused by an applied torque related to the measured force.

(vii) Measuring the change in natural frequency of a wire tensioned by the force.

Q.34. What are load cells ? Give their constructional features.

Ans. Load cells are elastic devices which are used for force measurement through indirect methods, i.e. using secondary transducers. They use an elastic member as the primary transducer and strain gauges as secondary transducers. The load cells can be operated by hydraulic or pneumatic pressures.

Strain gauges may be attached to any elastic member on which there exists a suitable plane area to accommodate them. This arrangement may then be used to measure loads applied to deform or deflect the member, provided that the resultant strain is large enough to produce detectable output.

The factors which are considered in the design of load cells using strain gauges are stiffness of elastic member, optimum positioning of gauges on the member and provision for temperature compensation. The stiffness of the elastic member should be such that it produces a deflection which is compatible with the range of the transducer. Thus, the gauges must be subjected to strains of sufficient magnitude to give a measurable output from the strain gauge bridge. A bridge with four active gauges is used to obtain maximum sensitivity.

An additional advantage of this bridge is that it provides complete temperature compensation.

Strain gauge transducers can measure a very wide range of forces. In fact, theoretically there is upper limit, as the elastic member may be made as robust as possible to withstand the load. The lower limit is determined by the sensitivity of the gauges.

Q.35. Discuss any three methods of force measurement in brief.

Ans. Three commonly used methods of force measurement are discussed below –

(i) ***Balance*** – A simple lever system shown in fig. 2.9, called as balance, has long been used as a force measuring device.

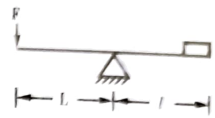


Fig. 2.9

To measure the unknown force F at a distance L from the pivot, a mass m at a distance l from the pivot is used. The system is in equilibrium when

$$FL = mgl \quad ...(i)$$

Several versions of such balances are available for various force ranges and degrees of accuracy.

(ii) Hydraulic Load Cell – In this device, hydraulic pressure is used to indicate the force F, applied to a diaphragm or some other type of force transmitting element. When force F is applied, pressure is developed in the fluid which is normally an oil. This can be measured by a pressure indicating device like a Bourdon gauge. Such a device can be used upto very large forces, of the order of millions of newtons.

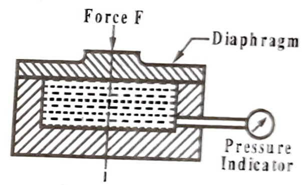


Fig. 2.10 Hydraulic Load Cell

(iii) Pneumatic Load Cell – In this type of load cell air is supplied under pressure to a chamber having a diaphragm at one end and a nozzle at the other. Application of force to the diaphragm deforms it and changes the gap between the extension of the diaphragm and the nozzle, thus changing the pressure in the chamber. If force F increases, the gap reduces and this increases pressure p_2 in the chamber. This increase in pressure produces a force tending to return the diaphragm to its original position. For any force F, the system attains equilibrium and pressure p_2 gives an indication of the force F. This type of load cell is used upto 20 kN.

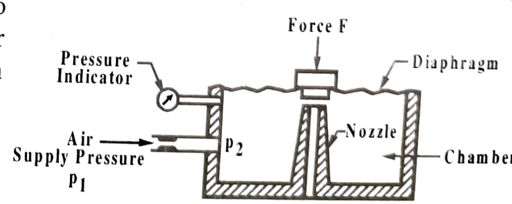


Fig. 2.11

Q.36. What is torque ? What are the methods of measuring the torque? ***(R.G.P.V., Dec. 2017)***

Ans. The torque is the torsional twisting moment or couple which tends to twist a rigidly fixed body, such as shaft turning about its axis of rotation. The application of a torque creates an angular displacement of the body about its axis of rotation. The measurement of torque is required in many engineering fields, especially in rotating machines. There are various methods that can be used for measurement of torque – mechanical, electromechanical or electronic methods.

Torque is measured by measuring force at a known distance. Torque is given by,

$$T = F.r$$

where, F = Force

r = Distance at which force is measured in case of shaft it is equal to shaft radius.

The methods of measurement of torque of rotating shafts of machines may involve –

(i) A power source: the machine which supplies power

(ii) A power sink: the machine which absorbs power

(iii) A power transmitter: the device which connects source and sink, and enables power transmission between them.

The arrangement showing source, sink and transmitter is given in fig. 2.12.

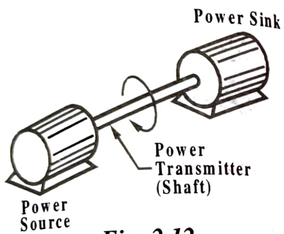


Fig. 2.12

For torque measurement, instruments used are strain gauges, inductive transducers, magneto-strictive transducers, electronic techniques, strain gauged load cells, etc.

Q.37. What is the use of dynamometer ? ***(R.G.P.V., Dec. 2016)***

Ans. A dynamometer is a device used for measuring the forces or couples which tend to change the state of rest or of uniform motion of a body. It is essentially a brake, in which an additional device has been incorporated for measuring the frictional resistance. It is generally used in laboratories to determine the power developed by an engine.

Q.38. How are dynamometers classified ?

Ans. Dynamometers can be classified into three main types –

(i) Absorption dynamometers (ii) Transmission dynamometers

(iii) Driving dynamometers.

(i) Absorption Dynamometers – In absorption dynamometer, entire work done by the prime mover under test is absorbed by the frictional resistance and converted into the heat. It is used for measuring the output of machines developing moderate power. Various absorption dynamometers can be classified as follows –

(a) Mechanical friction dynamometer, such as prony brake dynamometer and rope brake dynamometer.

(b) Hydraulic friction dynamometer, such as Tesla fluid friction dynamometer and Froude water vortex dynamometer.

(c) Electrical dynamometer, such as swinging field dynamometer.

(ii) Transmission Dynamometer – In a transmission dynamometer, work done by the prime mover under test, is not wasted in friction, instead it is transmitted to some other machine to do some useful work, after it has been measured. However, a little power may be absorbed to overcome the inherent friction of dynamometer. They are suitable for measuring large powers and for heat run tests. Important transmission dynamometers are –

(a) Belt transmission dynamometer

(b) Epicyclic-train dynamometer

(c) Torsion dynamometer.

(iii) Driving Dynamometers – In these type of dynamometers, drive is obtained from the dynamometer itself or the dynamometer is the power generator, like an electric motor.

Q.39. Explain the construction, working and use of the prony brake dynamometer. ***(R.G.P.V., Jan./Feb. 2008)***

Ans. A prony brake dynamometer as shown in fig. 2.13, is the simplest type of dynamometer. It consists of two wooden blocks clamped together on a revolving pulley by means of nut and bolts.

Each of these blocks embraces less than half of the pulley. The pulley is fixed to the shaft of an engine whose power is required to be measured. The helical spring is provided between the nut and the upper block to adjust the pressure on the pulley to control its speed. A long lever is attached to the upper block. The lever carries a weight W at its outer end. Two stops S, S are provided to limit the motion of the lever.

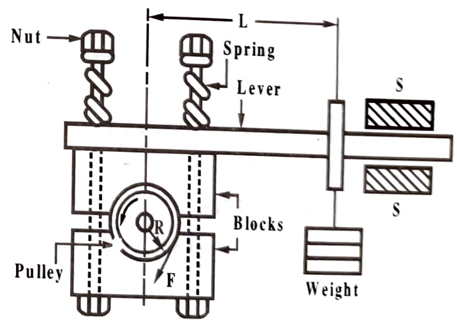


Fig. 2.13 Prony Brake Dynamometer

When the brake is to be put in operation, the friction between the blocks and the pulley tends to rotate the blocks in the direction of rotation of the shaft. To prevent this tendency, the long end of the lever is loaded with suitable weight

W and the nuts are tightened until the engine shaft runs at a constant speed and the lever is in horizontal position. Under these conditions, the moment due to the weight must balance the moment of the frictional resistance between the blocks and the pulley.

Let. F = Friction resistance between the blocks and the pulley, N
W = Weight applied at the end of the lever, N
L = Horizontal distance of the weight from centre of the pulley, m
R = Radius of the pulley, m
N = Speed of the shaft, r.p.m.

Now frictional torque acting on the shaft is given by,

$$T = W.L = F.R \text{ N-m}$$

and power of the engine under test,

$$P = T.\omega = \frac{2\pi NT}{60} = \frac{WL \times 2\pi N}{60} \text{ watts}$$

As we can see from the above equation, the power measured by this dynamometer is independent of the size of the pulley, coefficient of friction and pressure exerted by tightening of the nuts.

Prony brake dynamometer is used for measuring torque and power.

VERNIER CALIPER, MICROMETER, DIAL GAUGE

***Q.40. Describe vernier caliper with neat sketch.* (R.G.P.V., June 2014)**

Ans. A vernier caliper is a precision measuring instrument. A vernier caliper as shown in fig. 2.14 consists of a fixed and movable or sliding jaw. There is a main scale on the fixed jaw and a vernier scale on the sliding jaw.

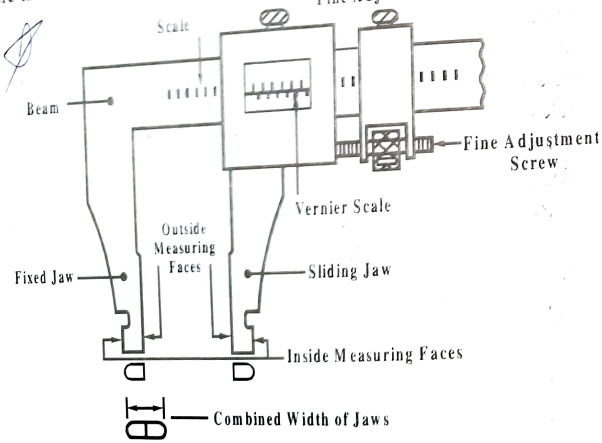


Fig. 2.14 Vernier Caliper

The main scale is marked in a similar manner to a rule and is graduated in millimetres. The vernier scale is marked into divisions slightly smaller than those on the main scale.

This instrument is widely used for precision measurement of length, thickness, depth and inside and outside diameter. Vernier calipers are available in different accuracies, i.e., 0.1, 0.02 mm and 0.05 mm. The vernier calipers those having a least count or accuracy 0.02 mm are most commonly used.

Q.41. Explain the operating procedure of vernier caliper.
(R.G.P.V., Dec. 2014)

Or

Discuss the measurement by vernier caliper with neat sketch.
(R.G.P.V., Dec. 2010)

Ans. In a vernier caliper as shown in fig. 2.14, the vernier scale is read in conjunction with the main scale. The main scale is marked in small divisions of 0.5 mm. Therefore,

$$1 \text{ division on vernier scale} = \frac{12}{25} \text{ mm} = 0.48 \text{ mm}$$

$\therefore$ 1 division of vernier scale is shorter than 1 division of main scale by

$$0.5 - 0.48 = 0.02 \text{ mm}$$

This is known as least count or accuracy of vernier calipers. This accuracy can be increased by increasing the length of the vernier scale.

To obtain the reading, the number of divisions of the main scale are first read off. The vernier scale is examined to determine which of its division coincide or most coincident with a division on the main scale. The number of these 0.02 divisions are added to the main scale reading to give the total reading.

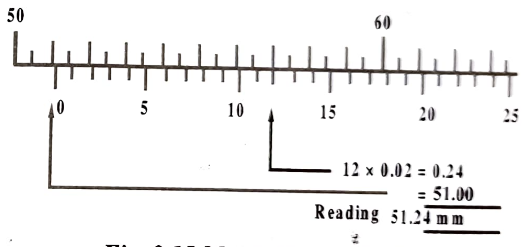


Fig. 2.15 Metric Vernier Scales

For example,

Reading on main scale = 51.00 mm
12 vernier divisions = $12 \times 0.02 = 0.24$
$\therefore$ Total reading = $51.00 + 0.24 = 51.24$ mm

Q.42. Give working principle of a micrometer.

Ans. The working of the micrometer depends upon the principle that the distance moved by the nut along the screw is proportional to the number of revolutions made by the nut. Thus, by controlling the number of revolutions and fractions of a revolution made by the nut, the distance moved by it along

(i) Check the zero reading.

(ii) Place the component to be measured in between the measuring faces.

(iii) Advance the spindle by rotating the ratchet until it begins to slip and clicks are heard. This shows that there is no further movement on the spindle. Note the readings both on barrel scale and on the circular scale of the thimble.

The micrometer reading = largest visible 'whole' millimetre + largest visible 'half' millimetre + thimble division coincident with the datum line.

Reading in fig. 2.17 is as follows –

8 whole millimetre = 8.00

1 'half' millimetre = 0.50

48 hundredths of a mm = 0.48

Thus, total reading = 8 + 0.50 + 0.48 = 8.98 mm

Q.46. What are dial gauges ? State its applications. (R.G.P.V., June 2016)

Ans. The dial gauge or dial test indicator is a mechanical device for sensing linear variations. It measures the displacement of its plunger or a stylus on a circular dial by means of a rotating pointer. Dial gauges are available for ranges of measurement of 0 to 3, 0 to 5 and 0 to 10 mm. These measurements indicate total movement lift of the plunger. Commonly used metric dial gauges have an accuracy of 0.01 mm.

A dial gauge found its application –

(i) To check the flatness of a surface.

(ii) To check the dimensions of a workpiece.

(iii) To check the parallelism of bar and rods.

(iv) To check the roundness of a component.

(v) For testing the machine tools.

Q.47. Give advantages and limitations of dial gauge.

***Ans.* Advantages of Dial Gauge –**

(i) Accuracy can be as high as 0.01 mm.

(ii) Operating range upto 100 mm.

(iii) Easy to read.

(iv) Quick in use if only comparison is required.

Limitations of Dial Gauge –

(i) Does not measure but will only indicate differences in size.

(ii) Easily damaged if mishandled.

(iii) Must be used with gauge blocks to determine measurement.

(iv) Must be rigidly supported in use.

(v) Loss of accuracy through number of moving parts.

Q.48. Explain the construction and working of a dial gauge

Ans. The essential parts of dial gauge are shown in fig. 2.18. Very slight upward pressure on the plunger moves it upward and the movement is indicated

by the dial pointer. The dial is graduated into 100 divisions. A full revolution of the pointer about this scale corresponds to 1 mm travel of the plunger. Thus a turn of the hand by one scale division represents a spindle travel of 0.01 mm. A revolution counter to indicate the travel of the plunger through whole millimetres is sometimes incorporated in the gauge on the big dial. The mechanism of dial gauge is shown in fig. 2.19. Movement of stem A is transmitted by means of a toothed rack through a compound gear train B and C to a pointer D, which moves around a dial face. The required measuring pressure is provided by a small spring incorporated in the mechanism.

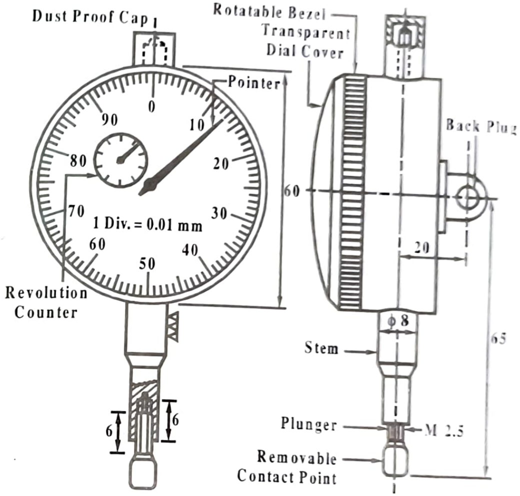


Fig. 2.18 Dial Gauge or Dial Test Indicator

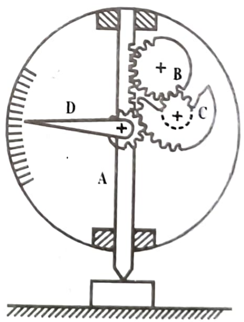


Fig. 2.19 Mechanism of Dial Gauge

The dial gauge is adjusted to zero by either turning the rim of the dial, or turning the head of the plunger while holding the dial gauge stationary.

Dial gauges are used to true and align machine tools, fixtures and work, to test and inspect the size and trueness of a finished work to an accuracy of 0.01 mm.

Q.49. Describe the construction and use of dial gauge.

(R.G.P.V., Dec. 2015)

Ans. **Construction of Dial Gauge** – Refer Q.48.

Uses of Dial Gauge – Dial gauge is extensively used in industries. Some uses are given as follows –

(i) To Check the Dimensions of Workpiece – Firstly, dial gauge is mounted on pillar stand. Now it is placed on known standard (i.e., slip gauges) and at this position, the pillar stand is locked so that dial gauge remain in same position. But before it, the reading of dial scale is set to zero and locked. Now dial gauge still having this position is crossed to the workpiece which is positioned on the same flat surface, any difference between the original setting and the face being checked can be read off the main scale. Refer fig. 2.20.

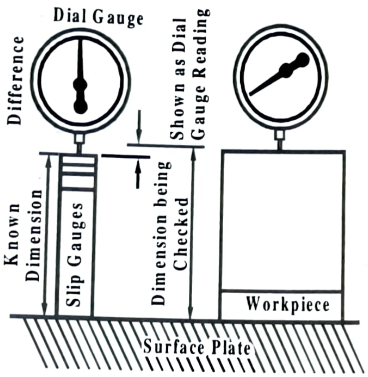


Fig. 2.20 Use of Dial Gauge to Check Dimension

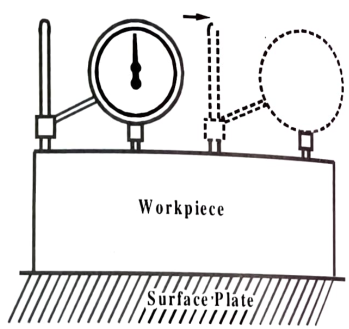


Fig. 2.21 Use of Dial Gauge to Check Parallelism

(ii) To Check the Parallelism of Workpiece – The dial gauge is set at one end of the component and the reading is noted. The plunger is then moved across the face of the workpiece, if the two faces are parallel the reading does not change. Refer fig. 2.21.

(iii) To Check the Roundness of a Component – The component, whose roundness is to be checked, is placed in vee block (shown in fig. 2.22). Now the dial gauge plunger is brought into contact with the upper face and datum reading can be taken. If the workpiece is now slowly rotated, the dial gauge pointer remains stationary for a truely round surface.

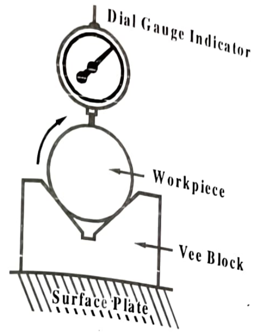


Fig. 2.22 Use of Dial Gauge to Check Roundness

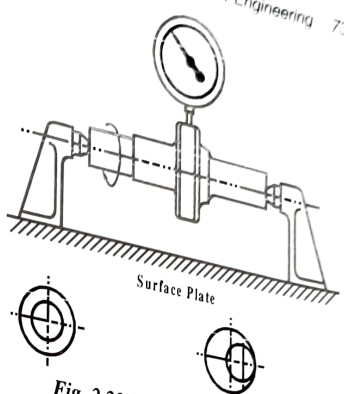


Fig. 2.23 Use of Dial Gauge to Check Concentricity

(iv) To Check the Concentricity of a Shaft – A shaft is said to be concentric when diameter of its both ends are on same central axis. To check the concentricity of a shaft the workpiece is mounted between centres which lie on the centre line of the component. Now the plunger of dial gauge is brought into contact with each diameter in turn, the workpiece can be slowly rotated. For true concentricity, the pointer on the main scale remains stationary. Refer fig. 2.23.

Q.50. Explain the construction and uses of the following measuring instruments –

(i) Dial gauge ***(ii) Micrometer.*** ***(R.G.P.V., June 2012)***

Ans.(i) ***Dial Gauge*** – Refer Q.48 and Q.49.

(ii) Micrometer – Refer Q.44 and Q.45.

SLIP GAUGES, SINE BAR AND COMBINATION SET

Q.51. Define the following –

(i) Slip gauges (ii) Angle gauges.

Ans. ***(i) Slip Gauges*** – The slip gauges or gauge blocks are rectangular blocks made of alloy steel having a cross-section of about 30 mm × 10 mm. They are hardened and finished to a high degree of accuracy. The size of the slip gauge is determined by the distance between two opposite faces.

(ii) Angle Gauges – An angle gauge is a hardened steel block approximately 75 mm long and 16 mm wide which has two lapped flat working faces lying at a very precise angle to each other.

Angle gauges are supplied in sets and can be wrung together to form desired angles. They are available in thirteen piece set, which also includes a square block.

Q.52. Write short note on – slip gauges. ***(R.G.P.V., June 2013)***

Ans. Slip gauges or gauge blocks are the universally accepted standards of length in industry. They are the working standards of linear dimension. Since the slip gauges are items of universal interchangeability, they are made in inch and mm according to IS, BS, DIN; and other national standards. In designation of a set of slip gauges, letter E is used for inch units and letter M is used for metric units. Number of pieces in a set following the letter E or M. For example, E 35 refers to a set whose blocks are in inch unit and are 35 in number. Similarly M87 refers to a set whose blocks are in mm units and are 87 in number.

Sets available in inch unit are –

E 81, E 49, E 41, E 35, E 28

Sets available in metric units are –

M112, M105, M87, M50, M33, M27, M86, M45 and M38.

Most slip gauges are produced from high grade steel. They are hardened and stabilised by a heat treatment process to give a high dimensional accuracy and stability. Slip gauges are also manufactured from tungsten carbide, which is an extremely hard and wear resistant material, although these are initially more expensive than the steel gauges. Sometimes the slip gauges are chrome plated. Chrome plating obviously eliminates the danger of corrosion.

All above metric sets are 1 mm based sets, i.e., the smaller length pieces have a basic length of 1 mm. In industrial practice, however is to use 2 mm based sets because these are less costly and likely to suffer less deterioration in flatness than similar size series based on 1 mm increments. In such a case the designation of M33 set will become M33/2 emphasizing that the set is 2 mm based.

The slip gauges are made in five grades of accuracy. The higher grades of accuracy, namely 'calibration-grade' and 'grade-00' are used in conjunction with high-magnification comparators. The lower grades of accuracy, namely grade-0, grade-I and grade-II are intended to be used as –

(i) Grade-0 slip gauges are used in workshop for inspection and high accuracy work.

(ii) Grade-I slip gauges are used for the measurement of components, tools and gauges.

(iii) Grade-II slip gauges are used in the workshop for rough checks.

Uses of Slip Gauges – Slip gauges are used for the following purposes –

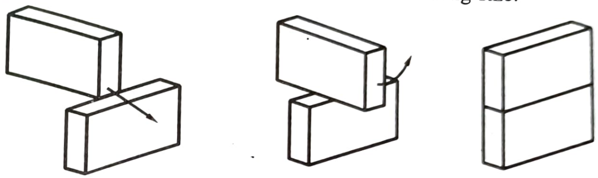
(i) For direct precise measurement where the accuracy of the workpiece demands it.

(ii) For use with high magnification comparators, to establish the size of the slip gauges in general use.

Slip gauges are also used for checking the accuracy of a measuring instrument or setting up a comparator to a specific dimension, enabling a batch of components to be quickly and accurately checked.

Q.53. Explain procedure of wringing of slip gauges.

Ans. Start wringing with the largest sizes first. Avoiding touching the measuring faces with fingers and handling the gauges as little as possible. Place two faces together at right angles and with pressure, twist through 90°. The action should be smooth and with constant pressure. Any feeling of roughness will show probable dirty or damaged faces and the action must be stopped and the gauge faces examined. When the largest gauges have been assembled, follow with the others in order of decreasing size.



(a) ***(b)*** ***(c)***

Fig. 2.24 Sequence of Wringing Operations

Q.54. What factors should be considered for care of slip gauges ?

Ans. The following points should be considered in care of slip gauges –

(i) Gauges should be stored in a box when not in use.

(ii) Measuring faces should not be touched with fingers.

(iii) Gauges should not be wrung together over an open box of gauges.

(iv) Accuracy of gauges should be checked at proper intervals.

(v) It is important that the measuring faces are clean and undamaged before wringing gauges together.

(vi) Gauges should not be wrung together for longer than is necessary.

(vii) The gauges and their case should be protected from dust and dirt.

(viii) As far as possible, the gauges should be used in air conditioned rooms free from dust and maintained at constant temperature.

(ix) Every care should be taken to protect the gauges from getting magnetised, otherwise, they will attract metallic dust.

(x) During actual use the gauge blocks with their working surfaces should never be placed on the surface plates etc.

Q.55. What is a sine bar ? Give its working principle.

Ans. A sine bar is essentially a hardened steel beam mounted on two hardened cylinders at a known distance. The holes are drilled to make it lighter.

Sine bar consists of a lapped steel bar. An accurate cylinder is attached at the each end of sine bar. The axes of cylinders are mutually parallel to each other and parallel to upper surface. Cylinders are attached at a distance of 100 mm to 250 mm. Sine bar having cylinders distance 100 mm is known as "100 mm sine-bar." A sine bar is shown in fig. 2.25.

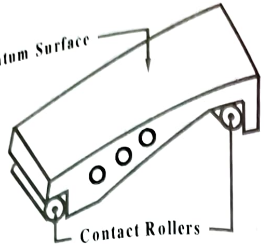


Fig. 2.25

The principle of sine bar is based on the trigonometry.

In right angled triangle ABC shown in fig. 2.26.

$$\frac{BC}{AC} = \sin\theta \text{ or } \theta = \sin^{-1}\left(\frac{BC}{AC}\right)$$

Length BC is generally adjusted by the slip gauges and length AC is length of sine bar. Therefore by calculating the ratio of BC to AC, the value of θ can be determined.

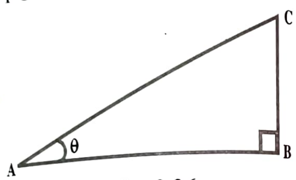


Fig. 2.26

Sine bar is used for precise measurement of angles of any component whose surface is accurately smooth. Sine bar is used in conjunction with slip gauges, dial gauges and surface plate etc.

Q.56. What is the use of sine bar ? State the process to measure any angle using sine bar with neat sketch. ***(R.G.P.V., June 2011)***

Ans. A sine bar is basically used for precise measurement of angles of any component whose surface is accurately smooth. It is used in conjunction with slip gauges, dial gauges and surface plate. Three most common uses of sine bar are as follows –

(i) To calculate the angle of a small component.

(ii) To calculate the angle of a large component.

(iii) To calculate the angle of taper plug gauge.

Method of measurement the angle of a small component using sine bar is discussed below –

Sine bar is used in conjunction with surface plate, slip gauges and dial indicator. Firstly, the component whose angle is to be measured, is mounted on sine bar as shown in fig. 2.27, then one

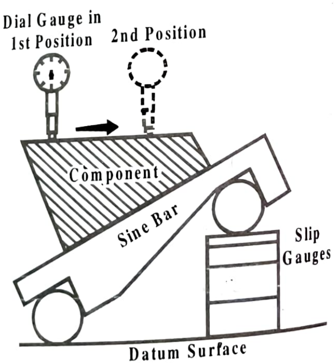


Fig. 2.27

side of sine bar is raised by means of slip gauges until the work surface is parallel to the datum surface. To check the parallelism of work surface, the dial gauge is used.

Therefore,

$$\theta = \sin^{-1}\left(\frac{H}{L}\right)$$

where, H = Total height of slip gauges

L = Sine bar length.

Q.57. With neat sketches, explain the use of sine bar to calculate –

(i) The angle of a large component

(ii) The angle of taper plug gauge.

Ans. (i) To Calculate the Angle of Large Component – When the component is so large that it cannot be mounted on sine bar, the sine bar can be mounted on the component as shown in fig. 2.28. The height of the rollers is measured by means of vernier height gauge. Therefore,

$$\theta = \sin^{-1}\left(\frac{h_1 - h_2}{L}\right)$$

(ii) To Calculate the Angle of Taper Plug Gauge – Arrangement for measurement of taper plug gauge is shown in fig. 2.28.

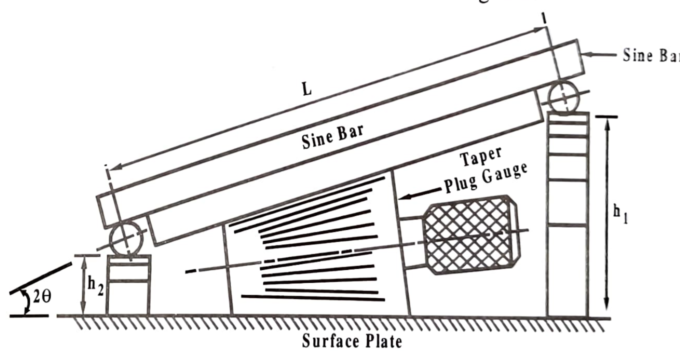


Fig. 2.28 Measurement of Taper Angle of Taper Plug Gauge

The taper angle of the taper plug gauge will be given as

$$2\theta = \sin^{-1}\left(\frac{h_1 - h_2}{L}\right)$$

where, 2θ = Cone angle of taper plug gauge

h_1 = Height of the slip gauge pile at one end

h_2 = Height of the slip gauge pile at other end.

Q.58. Explain how sine bar used for setting an angle and for finding an unknown angle. ***(R.G.P.V., Dec. 2015)***

Ans. Use of Sine Bar for Setting an Angle – A sine bar can be used to precisely set out any angle. For that purpose, the sine bar is first placed on a surface plate. After that slip gauges of the height required to produced the desired angle are placed under the one roller and opposite the angle θ as shown in fig. 2.29. The centre distance between the rollers (L) which is known will be the hypotenuse and the required perpendicular or height of slip gauges (H) can be determined using the relation.

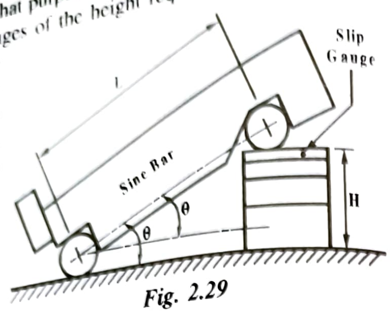


Fig. 2.29

$$\sin\theta = \frac{H}{L}$$

(ii) Use of Sine Bar for Finding an Unknown Angle – Refer Q.56.

Q.59. Explain the uses of sine bar. ***(R.G.P.V., June 2013)***

Ans. Refer Q.56 and 57.

Q.60. Give the labelled diagram, method of use and application of sine bar. ***(R.G.P.V., June 2015)***

Or

What is a sine bar ? Explain its use with the help of neat diagram. ***(R.G.P.V., Dec. 2011)***

Ans. Refer Q.55, Q.56 and Q.57.

Q.61. Differentiate between the following instruments –
(i) Sine bar (ii) Sine table (iii) Sine centre. ***(R.G.P.V., March/April 2010)***

Ans. (i) Sine Bar – Refer Q.55.

(ii) Sine Table – Usually sine tables are used to measure angles in two planes (i.e. compound angles) but it can also be used for linear as well as radial measurement.

Fig. 2.30 shows the use of sine table for linear measurement. The set up for measuring the thickness t at the zero mark on the tapered block A, the taper being 0.0025 in/in or 0°3'26". The table is tilted to angle θ, i.e. $\tan^{-1}$ 0.0025 equal to 3'26" by means of slip gauges pile, the height of which is L sin θ. The face PN is then parallel to the base RS

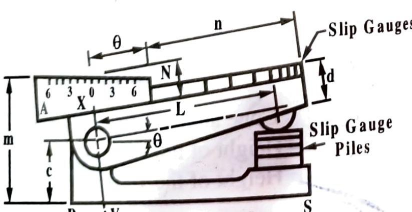


Fig. 2.30 Sine Table

of the table, and the height m can be measured without difficulty. The thickness t of the taper block is then equal to (m – c)/cos θ – d.

(iii) Sine Centre – It is difficult to mount conical work on sine bar, in this case sine centres are used. Sine centres consist of a self contained sine bar, hinged at one roller and mounted on its own datum surface. The top surface of the bar is provided with a pair of centres for holding the work as shown in fig. 2.31. Due to the work being hold axially between centres the angles of inclination will be half the included angle of the work.

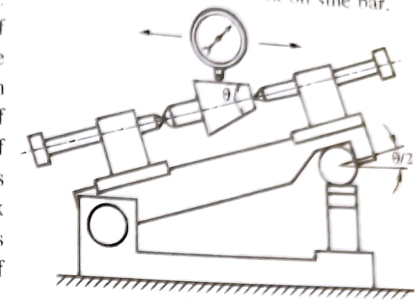


Fig. 2.31

Sine centres provide a conventional method of measuring the angle of taper plug gauge.

Q.62. What precautions should be taken while using sine bar for checking angular dimensions ?

Ans. Precautions while using sine bar for checking angular dimensions are as follows –

(i) The rollers must be of the same diameter.

(ii) The distance between their centres, i.e. 100 mm or 250 mm must be absolutely correct.

(iii) The centre line of roller centres must be absolutely parallel with bottom and top edges of the bar.

(iv) The measuring faces of the slip gauges should be clean and undamaged before wringing together. If difficulty is experienced then the measuring faces should be closely examined for small scratches.

(v) Measuring faces of the gauge blocks should not be fingered, so that the risk of tarnishing is minimised.

(vi) In slip gauge pile the large size gauge is placed at the bottom and small gauge at the top.

(vii) Every care should be taken to protect the gauges from getting magnetised, otherwise they will attract metallic dust.

Q.63. Explain the construction and use of a combination set. ***(R.G.P.V., Dec. 2012)***

Ans. A combination set is the common commercial variation of the steel rule with attachments. This is very useful instrument frequently used in the fitting and machine shop. It consists of the steel rule, the centre head, the sliding head or beam, the protractor head and a scriber. The three heads are used separately being held in at any desired position by nuts which

engage in a slot machined on the whole length of the beam at its back. The beam of the combination set which acts as a rule is marked either in inches or centimetres or in both for measuring the length and height as and when required. Length of the rule varies from 20 to 600 cm. A combination set is shown in fig. 2.32.

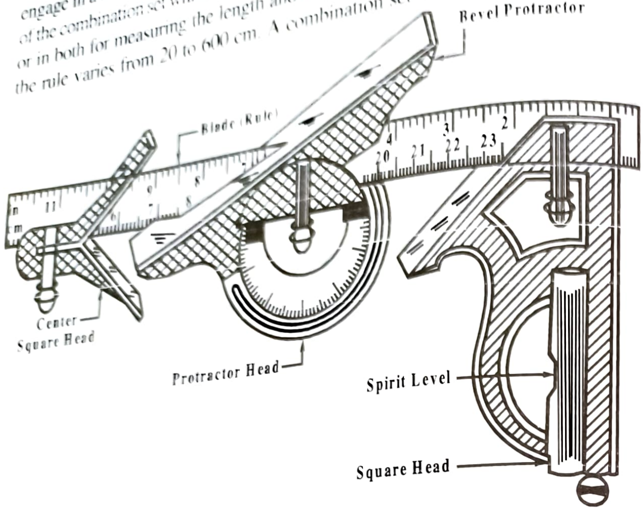
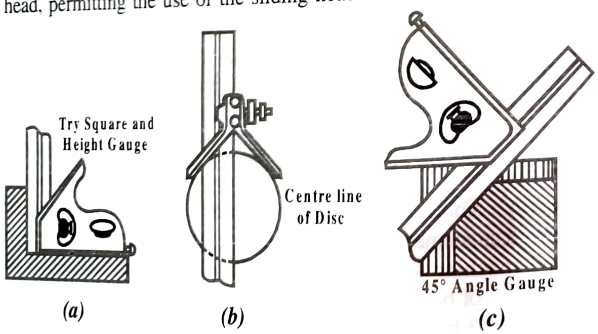


Fig. 2.32 Combination Set

It is possible to use the steel rule and the sliding head to square a piece with a surface and at the same time determine whether one or the other is plumb. Also by using the meter, it is possible to layout 45° angles as well as 90° angles with the head [fig. 2.33 (c), (f)]. A scriber is inserted conveniently in the head for this purpose. By setting the steel rule flush with the sliding head, it may be used as a height gauge directly [fig. 2.33 (a)]. Also by loosening the rule it is possible to use the combination set as a depth gauge where micrometer accuracy is not necessary [fig. 2.33 (d)]. The steel rule can be removed from the head, permitting the use of the sliding head and the rule separately. The



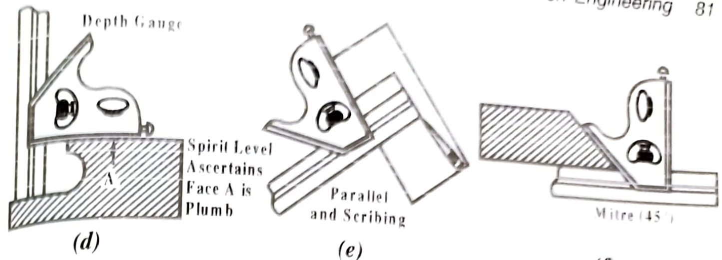


Fig. 2.33 Uses of a Combination Square

head can be used as an ordinary level. By substituting the centre head for the sliding head, a centre square is obtained for finding the centre line of cylindrical components [fig. 2.33 (b)]. The centre head is slotted in the centre so that the rule, when inserted, bisects the 90° angle. In this way the measuring surfaces become tangent to the circumference of cylindrical objects. It is possible to locate the centre of a bar.

The protractor can be inserted on the steel rule in the same manner as the centre head and the sliding head. The revolving turret can be graduated in degree from 0 to 180 or to 90 in either direction. Also the head contains a spirit level to facilitate the measuring of angles in relation to the vertical or horizontal plane.

Q.64. With the help of a neat sketch, explain the working of a combination set, mentioning its uses. Also give a neat sketch of a sine bar set up for measuring an angle of a workpiece. ***(R.G.P.V., Dec. 2013)***

Ans. Refer Q.63 and Q.56.

Q.65. Write a short notes on –

(i) Combination set (ii) Sine bar. ***(R.G.P.V., Dec. 2014)***

Ans. (i) Combination Set – Refer Q.63.

(ii) Sine Bar – Refer Q.55, Q.56 and Q.57.

NUMERICAL PROBLEMS

Prob.1. Find out the taper angle of workpiece if consecutive height of the two ends of sine bar from the surface plate is given as 10 cm and 5 cm. The length of sine bar is 10 cm. ***(R.G.P.V., June 2010)***

Sol. Given, $h_1 = 10$ cm, $h_2 = 5$ cm, $L = 10$ cm.

We know that, taper angle of workpiece

$$\theta = \sin^{-1}\left(\frac{H}{L}\right)$$

Since, net height. $H = h_1 - h_2$
$= 10 - 5 = 5$ cm

$\therefore \quad \theta = \sin^{-1}\left(\frac{5}{10}\right) = 30°$ **Ans.**

ELEMENTARY THEORETICAL ASPECTS OF PRODUCTION PROCESSES LIKE CASTING, CARPENTRY, WELDING, ETC.

Q.66. What is casting ?

Ans. In casting, the molten metal is poured into a refractory mould with a cavity of the shape to be made, and allowed to solidify. After solidification, the desired metal object is taken out from the mould. The solidified object is known as casting. Sand moulds are generally used for casting, however, they cannot maintain better tolerances and smooth surface finish. Thus, now-a-days metallic moulds are more common.

Q.67. What are the advantages and disadvantages of casting processes ?

Ans. **Advantages of Casting Process –**

(i) Casting is one of the most versatile manufacturing processes.

(ii) Casting can be used for any intricate shape internal or external, and any material whether ferrous or non-ferrous can be cast.

(iii) Tool required for casting moulds are very simple and inexpensive.

(iv) Shapes difficult and uneconomical to obtain by other methods can be obtained by casting.

(v) Very heavy and bulky parts (like those of power plants and mill housings) which are otherwise difficult to get fabricated may be cast.

(vi) With the casting process, it is possible to place the amount of material where exactly required. Thus, a weight reduction in design can be achieved.

(vii) Castings generally do not have directional properties, because they are cooled uniformly from all sides.

(viii) Castings can be designed for equal distribution of loads (on all members of a product) and minimum stress concentration in order to achieve more strength and increased service life.

(ix) The number of castings can vary from a single item to several thousands.

Disadvantages of Casting Process –

(i) For many applications, the dimensional accuracy and surface finish may not be adequate.

(ii) Sand casting process is labour intensive.

(iii) A complicated sequence of operations may be required for metal casting.

(iv) With some materials it is often difficult to remove defects arising out due to the moisture present in sand castings.

Q.68. Enlist various methods of casting. Define any one of them.

Ans. Various methods of casting include –

(i) Die casting
(ii) Centrifugal casting
  (a) True centrifugal casting
  (b) Semicentrifugal casting
  (c) Centrifuged.
(iii) Investment casting
(iv) Continuous casting
(v) Malleable casting.

Die Casting – In die casting, the molten metal is forced under pressure into split metal dies which resemble a common type of permanent mould. Within a fraction of a second, the fluid alloy fills to entire die containing all the minute details. Due to the low temperature of the die, the casting solidifies quickly, permitting the die halves to be separated and the casting ejected. If the parts are small, several parts may be cast at one time by using multiple cavity die.

This process is particularly suitable for lead, magnesium, tin, and zinc alloys. The advantage of die casting practice lie in the possibility of obtaining castings of sufficient exactness and is the facility for casting thinner sections that cannot be produced by any other casting method.

Q.69. Differentiate between moulding and casting.

Ans. The casting process has the following plus points, as compared to the moulding –

(i) The process is particularly suited to the parts which contain internal details that are too complex, too large or inaccessible, to be easily produced by the machining process.

(ii) The casting process is advantageous to cast complex parts in large numbers, especially of non-ferrous metals and their alloys.

(iii) For producing one of a kind part, in a variety of materials.

(iv) For processing precious metals, since there is little or no loss of material.

(v) Parts made by casting process are isotropic, which can be an important characteristic in some applications.

Q.70. State advantages and disadvantages of die casting.

Ans. Advantages of die casting are –

(i) Very high rate of production is achieved.

(ii) Close dimensional tolerances of the order of ±0.025 mm is possible.

(iii) Surface finish of 0.8 microns can be obtained.
(iv) Very thin sections of the order of 0.50 mm can be cast.
(v) Fine details may be produced.
(vi) Longer die-life is obtained.
(vii) Unit cost is minimum.

Disadvantages of die casting are –

(i) Not economical for small runs.
(ii) Only economical for non-ferrous alloys.
(iii) Heavy castings cannot be cast. In fact, the maximum size is limited by the size of the dies and the capacity of the die casting machines available.
(iv) Cost of die and die casting equipment is high.
(v) Die casting usually contain some porosity due to the entrapped air.

Q.71. Explain centrifugal casting and its types.

Ans. In the centrifugal casting, molten metal is poured into moulds while they are rotating. The metal falling into the centre of the mould at the axis of rotation is thrown out by the centrifugal force under sufficient pressure towards the periphery, and the contaminants or impurities present being lighter in weight are also pushed towards the centre. This is often machined out any way. Solidification progresses from the outer surface inwards, thus developing an area of weakness in the centre of the wall. This is caused by the meeting of the grain boundaries at final solidification and the entrapment of impurities in the central section. The grains are refined and the castings are completely free from any porosity defect by the forced movement of the molten metal, thus making dense and sound castings which are less subjected to directional variations than static castings. The use of gates, feeders, and cores is eliminated, making the method less expensive and complicated.

Hollow cylindrical bodies such as cast iron water supply and sewerage pipes, steel gun barrels, and other symmetrical objects, such as gears, disk wheels, pulleys are convenienty cast without core by the centrifugal casting.

Centrifugal casting can be classified into following three types –

(i) True centrifugal casting (ii) Semicentrifugal casting
(iii) Centrifuged.

(i) True Centrifugal Casting – This employs moulds of rotational symmetry made of steel or graphite. The melt is poured while the mould rotates at its axis, which may be horizontal, vertical or inclined at any suitable angle between 0 to 90°, although horizontal axis of rotation is a more common practice. While rotating, the molten metal is carried to the walls of the cavity by centrifugal force. The metal then solidifies forming a hollow casting without the use of a central core. The outside of the mould is water cooled to accelerate solidification. By proper control of flow rates and movement of the pouring orifice, long and large tubes of very uniform quality and wall thickness can be cast. If desired, the outer contour of the casting can be varied, while the inside remain cylindrical.

This method is ideal for hollow cylindrical castings such as bushings, gun barrels, cast iron pipes, etc.

(ii) Semicentrifugal Casting – This is used for forming symmetrical shapes about the rotative axis, which is usually vertical in a balanced state. The molten metal is introduced through a gate which is placed on the axis, and flows outward to the rim by the centrifugal force. If a central bore is required in the casting, a dry sand core is best suited. The central gate acts as a riser for the hub portion.

This method is generally employed for making large-sized castings which are symmetrical about their own axis such as gears, disked wheels, propellers and pulleys.

(iii) Centrifuged – In this process several identical or nearly similar moulds are located radially about a vertically arranged central riser or sprue which feeds the metal into the cavities through a number of radial gates. The entire mould is rotated with central sprue which acts as the axis of rotation. Thus, it is not a purely centrifugal process.

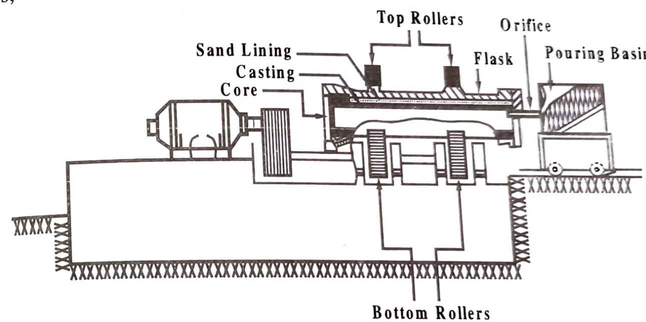


Fig. 2.34 Centrifugal Casting

This type of casting is suitable for small, intricate parts where feeding problems are encountered. This method can be used to advantages for stack moulding of six or more moulds mounted one above the other.

Q.72. Explain the different types of pattern allowances.

(R.G.P.V., Dec. 2017)

Ans. Patterns are usually made of size larger than the actual required size of the casting. This is called providing allowances. Allowances are mainly provided to compensate the effect of solidification of metal to be cast otherwise the actual product will be of undersize.

Various types of allowances which are usually provided on a pattern are –

(i) Shrinkage allowance (ii) Draft allowance
(iii) Machining allowance (iv) Distortion allowance
(v) Rapping allowance.

These allowances are discussed below –

(i) ***Shrinkage Allowance*** – As metal solidifies and cools, it shrinks and contracts in size. To compensate for this, a pattern is made larger than the finished casting by means of a shrinkage or contraction allowance in laying measurements for the pattern the pattern maker allows for this by using shrink or contraction rule which is slightly longer than the ordinary rule of the same length. For example, when constructing a pattern for cast iron, the pattern maker uses a shrink rule measuring about 10 mm longer per metre than the conventional rule since cast iron shrinks 10 mm per metre. Different metals have different shrinkages, therefore there is a shrink rule for each type of metal used in a casting. A master pattern from which metal patterns are cast may have double shrinkage allowance.

(ii) ***Draft Allowance*** – When a pattern is drawn from a mould, there is always some possibility of injuring the edges of the mould. This danger is greatly decreased if the vertical surfaces of a pattern are tapered inward slightly. This slight taper inward on the vertical surfaces of a pattern is known as the draft. Draft may be expressed in millimetre per metre on a side, or in degrees, and the amount needed in each case depends upon –

(a) Length of the vertical side
(b) Intricacy of the pattern
(c) The method of moulding.

Under normal conditions the draft is about 10 to 20 mm per metre on exterior surfaces and 40 to 60 mm per metre on interior surfaces.

(iii) ***Machining Allowance*** – Rough surfaces of castings that have to be machined are made to dimensions somewhat over those indicated on the finished working drawings. The extra amount of metal provided on the surfaces to be machined is called machine finish allowance and the edges of these surfaces are indicated by a finish mark V, or F. The amount that is to be added to the pattern depends upon –

(a) The kind of metal to be used
(b) The size and shape of the casting
(c) Method of moulding.

(iv) ***Distortion or Camber Allowance*** – Some castings, because of their size, shape and type of metal, tend to warp or distort during the cooling period. This is a result of uneven shrinkage and is due to uneven metal thickness or to one surface being more exposed than another, causing it to cool more rapidly. The shape of the pattern is thus bent in the opposite direction to overcome this distortion. This feature is called ***distortion*** or ***camber allowance***.

(v) ***Rapping or Shaking Allowance*** – A pattern is shaken or rapped by striking it with a wooden piece from side to side. This is done so that the pattern is loosened a little in the mould cavity and can be easily removed. But rapping enlarges the mould cavity which results in a bigger sized casting. Hence a negative allowance is provided on the pattern, i.e. the pattern dimensions are kept smaller in order to compensate the enlargement of mould cavity due to rapping. This is called rapping or shaking allowance. Shaking allowance is normally provided only to large castings because in case of small castings, it is negligible and can be ignored.

Q.73. What is carpentry ?

Ans. Wood obtained from the trees is the basic raw material for many of the home decore, commercial and industrial products. Any type of work with wood is termed as carpentry and joinery.

Carpentry involves cutting, shaping and fastening wood (any other materials) together to produce an article, while joinery deals with various joints required to make wooden articles. The carpentry is referred to the constructional work such as making roofs, floors, partitions, etc of a building by using wood and various carpentry tools. The term joinery deals with the making of doors, windows, cupboards, dressers, stairs and all the interior fitments for a building.

Q.74. Give a classification of carpentry tools.

Ans. Various tools used in carpentry may be classified into following main categories –

(i) Marking and measuring tools
- (a) Rules
- (b) Straight edge
- (c) Try square
- (d) Bevel square
- (e) Mitre square
- (f) Combination square
- (g) Marking gauge
- (h) Mortise gauge
- (i) Sprit level and plumb bob.

(ii) Cutting tools
- (a) Saws
- (b) Chisels
- (c) Axe.

(iii) Planing tools
- (a) Jack plane
- (b) Trying plane
- (c) Smoothing plane
- (d) Plough plane
- (e) Metal plane, etc.

(iv) Boring and drilling tools
- (a) Bradawl
- (b) Auger
- (c) Gimlet
- (d) Brace
- (e) Bits.

(v) Fixing and striking tools
- (a) Bench vice
- (b) T-cramp
- (c) G-cramp
- (d) Hammer
- (e) Mallet.

(vi) Miscellaneous tools
- (a) Screw driver
- (b) Pincer
- (c) Rasp and file
- (d) Scraper
- (e) Oilstone.

Q.75. Name various carpentry joints.

Ans. All wooden objects, like doors, windows, furniture, handicrafts, toys, etc are assembled with joints. Joints are used for framing, widening and lengthening of wooden objects. Various types of joints used in carpentry can be classified into two main classes, viz. framework and carcase work. Joints which come in framework include half-lap joint, mortise and tenon joint, and bridle joint.

Joints which come in carcase work are butt or rubbed joint, dowl joint, tongue and groove joint, and screw and slot joint.

Some other important carpentry joints are dovetail joint and corner joint.

Q.76. What is welding ? Give its applications.

Ans. The welding is a process of joining two similar or dissimilar metals by application of heat with or without the application of pressure and addition of filler material. Welding is mainly used for joining metals and their alloys, however it can also be used for joining of other materials such as thermoplastics.

Now-a-days welding is extensively used in fabrication of automobiles, aircrafts, ships, electronic equipment, machinery, home appliances etc., as an alternative of casting or forging or as a replacement of riveted or bolted joints. Welding is also used as a repair medium e.g., to reunite metal at a crack or to build up a small part that has broken off such as a gear tooth or a bearing surface.

Q.77. Give a detailed classification of welding processes.

Ans. Welding can be broadly classified into following two categories –

(i) Plastic welding (ii) Fusion welding.

(i) Plastic Welding – In plastic or pressure welding process, pieces of metal to be joined are heated to a plastic state and then forced together by external pressure. In this method no filler material is used. Plastic welding may be further classified as follows –

- Plastic or Pressure Welding
  - Blacksmith's Forge Welding
  - Resistance Welding
    - Spot Welding
    - Seam Welding
    - Projection Welding
    - Upset Butt Welding
    - Flash Butt Welding
    - Percussion Welding
  - Friction Welding
  - Cold Pressure Welding

(ii) Fusion Welding – In fusion or non-pressure welding, the edges of the workpieces to be joined are heated to a temperature above the melting point of metal and then allowed to solidify. A filler material is used during fusion welding. Fusion welding may be further classified as follows –

- Fusion or Non-pressure Welding
  - Electric Arc (A.C. or D.C.) Welding
    - Carbon Arc Welding
    - Metal Arc Welding
    - Submerged Arc Welding
    - Plasma Arc Welding
    - Inert Gas Welding
      - Tungsten Inert Gas Welding (TIG)
      - Metallic Inert Gas Welding (MIG)
    - Atomic Hydrogen Welding
  - Gas Welding
  - Thermit Welding

Q.78. Define weldability of metals.

Ans. Weldability is defined as the capacity of being welded into inseparable joints having specified properties such as definite weld strength, proper structure, etc. This means that if a particular metal is to have good weldability, it must be welded readily so as to perform satisfactorily in the fabricated structure. The real criterion in deciding on the weldability of a metal is the quality of weld and ease with which it can be obtained.

Weldability depends on the following –

(i) Thermal conductivity (ii) Melting point
(iii) Surface condition (iv) Thermal expansion
(v) Change in microstructure.

If these characteristics of a metal are considered undesirable with respect to weldability, they may be corrected by proper shielding atmosphere, proper welding procedure, proper filler metal, proper fluxing material and in some cases by proper heat treatment of the metal before and after deposition.

Q.79. What do you understand by gas welding ? Describe in brief.

Ans. Gas welding is a technique of fusion welding in which heat for welding is obtained by the combustion of a fuel gas. The edges or surfaces to be joined are melted by the heat of a gas flame at very high temperatures. The molten metal is allowed to flow together and a solid continuous joint is obtained when the molten metal solidifies. The gas welding is particularly suitable for

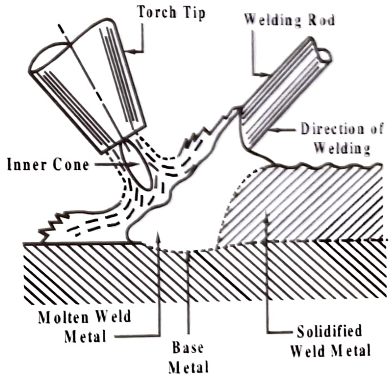


Fig. 2.35 Gas Welding

joining metal sheets and plates of thickness from 2 mm to 50 mm. For welding sheets of thickness more than 15 mm additional metal (known as filler metal) in the form of welding rod is melted into the gap between the two parts to be joined.

A flux is also used during welding to remove impurities and oxides present on the surfaces of metal to be joined so as to obtain a good weld quality. The principle of gas welding is shown in fig. 2.35.

Q.80. Describe in detail the process of oxy-acetylene gas welding.

Ans. In oxy-acetylene welding oxygen and acetylene gases are used for producing hot flame. Oxygen is usually prepared in factories by liquefying air and separating it into its component parts by rectification. From factories, it is available under high pressure in cylinders fitted with pressure regulators to obtain it at desired pressure for welding. Acetylene is also produced in factories, however it may also be produced at welding places for many applications.

The chemical reaction for complete combustion of oxygen and acetylene is as follows –

$$2C_2H_2 + 5O_2 \longrightarrow 4CO_2 + 2H_2O$$

Thus. for complete combustion, ratio of oxygen to acetylene is 2.5:1. But for most of the general welding purposes, oxygen and acetylene are mixed in equal proportions. Under this condition following chemical reactions takes place –

$$C_2H_2 + O_2 \longrightarrow 2CO + H_2$$

$$2CO + O_2 \longrightarrow 2CO_2$$

$$2H_2 + O_2 \longrightarrow 2H_2O$$

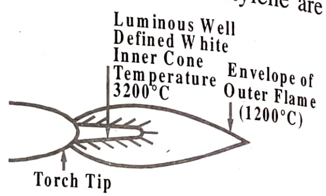


Fig. 2.36 Oxy-acetylene Gas Flame

As we can see complete combustion takes place in two phases. From the oxygen and acetylene as obtained from torch incomplete combustion takes place producing CO and H_2. This reaction takes place at inner cone of the flame, where the highest temperature is obtained, clearly visible by a well defined white inner cone (fig. 2.36). CO and H_2 produced in first stage further combine with atmospheric oxygen and give rise to the outer bluish cone. Temperature in the outer cone is about 1200°C.

When acetylene is mixed with oxygen in correct proportion in the welding torch and ignited, the flame is produced at tip of the torch, sufficiently hot to melt and join the parent metal. The oxy-acetylene flame reaches a temperature about 3200°C, thus can melt all commercial metals and causes them to flow together to form a complete bond. A welding rod of filler metal is generally added to the molten metal pool to have greater strength.

Q.81. What is arc welding ? Name various methods of arc welding.

Ans. In arc welding, heat required for welding is obtained by means of an electric arc formed between base metal and electrode. The workpiece and electrode act as two conductors of an electric circuit which are touched together and then separated at proper distance to produce an arc. This arc generates intense heat which quickly melts the work under it and forms a pool of molten metal, which get solidified during cooling.

Various arc welding methods are as follows –

(i) Carbon arc welding (ii) Metal arc welding
(iii) Metal inert gas arc welding (MIG)
(iv) Tungsten inert gas arc welding (TIG)
(v) Atomic hydrogen arc welding (vi) Plasma arc welding
(vii) Submerged arc welding (viii) Flux cored arc welding
(ix) Electro-slag welding.

Q.82. Explain briefly the procedure of manual arc welding process.

Ans. Arc welding is the most extensively used method of joining metal parts. Heat required for welding is obtained by means of an electric arc formed between base metal and electrode. The principle of arc formation is as follows –

When two conductors of an electric circuit are touched together and then separated by a small distance, sufficient to maintain the flow of current through the gaseous medium (air) an arc is produced. The temperature generated by this method is of the order of 6000-7000°C.

The electrode which also supplies the filler material is first make in contact with the workpiece and then separated at proper distance to produce an arc. The intense heat generated by arc quickly melts the work under it and forms a pool of molten metal, as shown in fig. 2.37.

The blast of the arc forces the molten metal out of the pool, thus forming a small depression in the parent metal, known as ***arc crater***, around which the molten metal is deposited. The distance through the centre of the arc from the tip of the electrode to the bottom of the arc crater, is termed as ***arc length***. Arc length should be kept 3 to 4 mm, so that the globules of molten metal during deposition should have the smallest possible chance of coming in contact with ambient air to avoid oxidation.

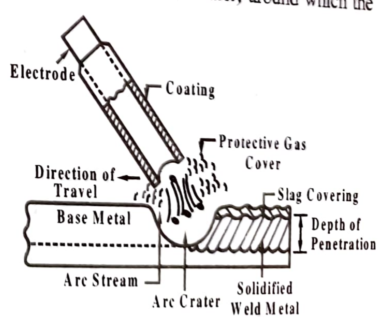


Fig. 2.37 Arc Welding

Both A.C. and D.C. supply can be used for arc welding. A.C. supply is made by means of a step down transformer, which reduces the main supply voltage 220-440 V to 80-100 V, required for striking the arc. To maintain the arc a still lower voltage about 30-40 V is required. D.C. supply is made by means of a generator, driven by either an electric motor or an I.C. engine. The voltage required in case of D.C. supply is 60-80 V for striking the arc and 15-25 V for maintaining the arc.

INTRODUCTION TO LATHE AND DRILLING MACHINES AND THEIR VARIOUS OPERATIONS

Q.83. Explain the principle of lathe machine with simple sketch. ***(R.G.P.V., March/April 2010)***

Ans. The lathe can be defined as a machine tool which holds the work between two rigid and strong supports called live centre and dead centre, out of which the former revolves. A lathe basically consists of a bed to provide support, a head stock, a cross-slide to traverse the tool, a tool post mounted on the cross slide. The spindle is driven by a motor through a gear box. The carriage moves over the bed guideways parallel to the workpiece and the cross slide provides the transverse motion. A feed shaft and a lead screw are also provided to power the carriage and for cutting the threads respectively.

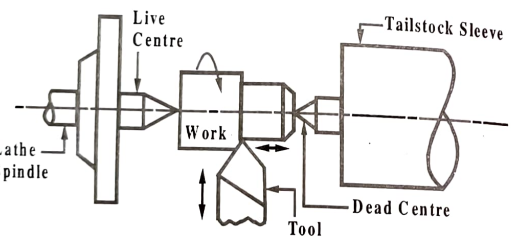


Fig. 2.38

Lathe removes undesired material from a rotating workpiece in the form of chip. The cutting tool is rigidly held and supported in a tool post and is fed against the rotating workpiece. While the workpiece rotates about its own axis the tool is made to move either parallel to or at an inclination with the axis.

Q.84. Name various types of lathe machines with their specific applications. ***(R.G.P.V., March/April 2010)***

Ans. The various types of lathe machines are given as follows –

(i) Low Production Type Lathes –

(a) Bench Lathe – It is used for small and precision work since it is very accurate.

(b) Toolroom Lathe – It is mainly used for precision work on tools, dies, gauges and in machining work where accuracy is needed.

(c) Speed Lathe – It is used for wood turning, polishing, centring and metal spinning, etc.

(d) Engine Lathe – The uses of engine lathe is similar to speed lathe.

(ii) Medium Production Lathes –

(a) Turret and Capstan Lathe – Turret lathe is used for mass production of identical components and can handle much larger and heavier jobs.

Capstan lathe is used for relatively lighter and smaller jobs, but for more precision work.

(b) Duplicating Lathe – It is used for mass production of identical parts where either a previously machined part works as a template or a separate template is prepared and used for this purpose.

(iii) High Production Lathe –

(a) Automatic Lathe – It is used for mass production and specially suitable for heavy duty and high speed works.

(iv) Special Purpose Lathes –

(a) Precision Lathe – It is used for precision turning of previously rough-turned workpieces. A high class grinding machine on account of its fine dimensional accuracy.

(b) Facing Lathe – It is used to machine the end faces of bulky cylindrical jobs.

(c) Frontal Lathe – It is used in machining the short jobs.

(d) Vertical Lathe – It is used for turning and boring very large and heavy rotating parts and it is specifically employed for jobs like heavy flywheels and large gear blanks, etc.

(e) Crankshaft Lathe – It is used for turning very long parts such as turbine, engine shafts and crankshafts.

(f) Screw Cutting Lathe – It is used for mass production of screwed parts. Specially suitable for precision screw work.

Q.85. With the help of a simple sketch, explain different components of a lathe machine. ***(R.G.P.V., June 2013)***

Or

Draw a neat sketch of lathe machine showing essential components. State functions of three major components. ***(R.G.P.V., June 2016)***

Ans. The lathe machine as shown in fig. 2.39 consists of following parts –

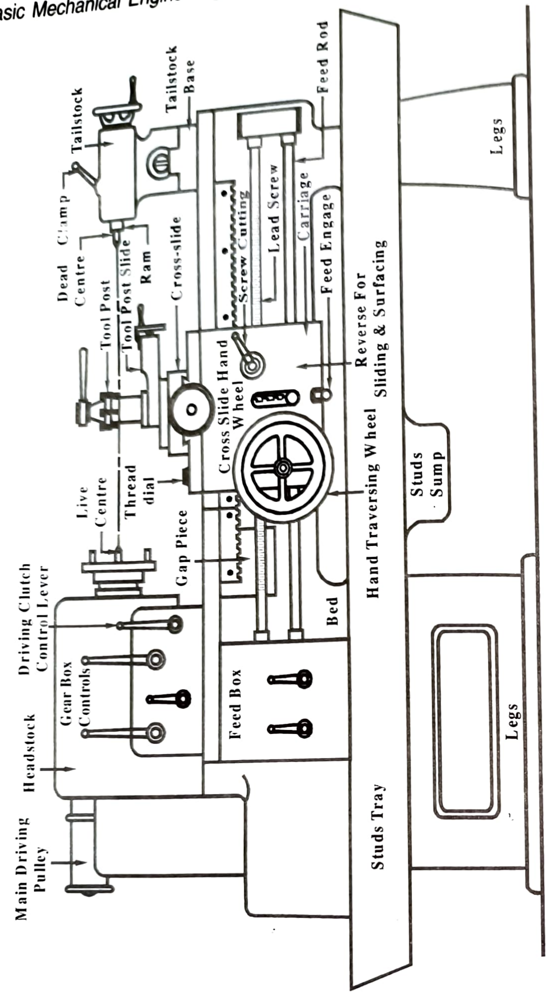


Fig. 2.39 The Lathe

(i) Bed **–** The bed is the base or foundation of the lathe. It supports the other parts i.e., headstock, tailstock and carriage etc. The bed is the main guiding member of the tool. The lathe bed must satisfy the following conditions for accurate machining –

(a) It should be sufficiently rigid to prevent deflection under tremendous cutting pressure.

(b) It must be massive with sufficient width and depth to absorb vibration.

(c) It must resist the twisting stress etc.

(d) The bed should be seasoned naturally to avoid distortion that may develop when it is cooled after the bed is cast.

The top of the bed is planed to form "guides" or "ways". Ways are accurate rails which support carriage and the tailstock.

The cast iron alloyed with nickel and chromium forms a good material suitable for lathe bed.

(ii) Headstock – The headstock assembly is permanently fastened at the left hand end of the lathe bed. It serves to support the first operative unit of the lathe, i.e., the spindle. The spindle revolves on two large bearings, one at each end of the headstock. The spindle is rotated by a combination of gears and cone pulleys or by gear alone. A hole extends through the spindle so that a long bar may be passed through the bore. The front end of the hole is appeared for holding centres and other tools having a standard morse taper shank. A taper sleeve fits into the taper hole and a live centre which supports the work and revolves with the work fits into the sleeve that acts as a bush.

(iii) Tailstock or Loose Headstock – The tailstock is located on the innerways at the right hand end of the bed. It serves to support the other end of the work and to hold a tool for performing operations such as drilling, reaming, tapping etc. The tailstock can be moved along the bed and clamped to the bed at the various desired locations to suit the length of the workpiece. Tailstock consists of two main parts. The lower part rests on the bed ways and the upper part rests on the lower part. The upper part can be moved towards or away from the operator to offset the tailstock for taper turning and to realign the tailstock centre for straight turning. The body of the tailstock has a bore for the hollow cylindrical sliding member, known as a "quill". This quill holds the cutting tools such as drills, reamers, taps etc., and feeds to the workpiece.

(iv) Carriage – It is fitted on the bed and slides along the bed guide ways and its purpose is to hold the cutting tool and to impart either longitudinal or cross feed. It has five major parts –

(a) Saddle – The base of the carriage is the saddle which slides along the ways between the headstock and tailstock.

(b) Cross-slide –The cross-slide is mounted on the saddle. It provides cutting tool motion which is perpendicular to the centre line.

(c) Compound Rest – It is mounted on top of the cross-slide. It has a circular base graduated in degrees. It is used for obtaining angular cuts and short tapers as well as convenient positioning of the tool to the work. The compound rest is operated by hand. It is equipped with a micrometer dial to assist in determining the depth of the cut.

(d) Tool Post – The tool post is mounted on the compound rest and slides in a T-slot. Cutting tool or tool holder is firmly held in it. The tool can be swivelled as well as tilted by means of a rocker and a concave ring collar.

(iv) ***Apron*** – The apron is fastened to the saddle and hangs over the front of the bed. It contains the gears, clutches and levers for operating the carriage by hand and power feeds.

(v) ***Feed Mechanism*** – The movement of the tool relative to the work is termed as "feed". A lathe may have three types of feed, i.e., longitudinal, cross and angular. In longitudinal feed, the tool moves parallel to the lathe axis. In cross feed, the tool moves at right angle to the lathe axis. In angular feed, tool is swivelled at an angle to the lathe axis. The feed mechanism has different units through which motion is transmitted from the headstock spindle to the carriage, such as – feed gear box, feed rod and lead screw, apron mechanism, quick change gear box and half nut mechanism.

(vi) ***Screw Cutting Mechanism*** – The rotation of the lead screw is used to transverse the tool along the work to produce screw thread. The half-nut mechanism makes the carriage to engage or disengage with the lead screw.

Q.86. Explain the construction and working principle of a lathe machine with neat sketch. ***(R.G.P.V., June 2008, Dec. 2012)***

Or

Explain the construction and working principle of a simple lathe machine. ***(R.G.P.V., June 2014)***

***Ans.* Construction of Lathe** – Refer Q.85.

Working Principle – Refer Q.83.

Q.87. Write the various operations that can be performed on the lathe machines. ***(R.G.P.V., Dec. 2017)***

Or

Explain various lathe operations in brief. ***(R.G.P.V., June 2015)***

Ans. The most common operations which can be carried out on a lathe are given as follows –

(i) Facing (ii) Plain turning
(iii) Step turning (iv) Drilling
(v) Reaming (vi) Boring
(vii) Undercutting (viii) Threading
(ix) Knurling.

(i) ***Facing*** – Facing operation is necessary for all works. In this, the workpiece is held in the chuck and the facing tool is fed from the centre of the workpiece towards the outer surface or from the outer surface to the centre, with the help of a cross-slide. This operation is shown in fig. 2.40.

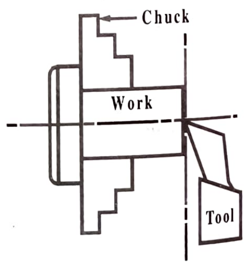


Fig. 2.40 Facing

(ii) ***Plain Turning*** – In this, the work is held either in the chuck or between centres and the longitudinal feed is given to the tool either by hand or power. It is an operation of removing excess amount of material from the surface of the cylindrical workpiece. Plain turning is shown in fig. 2.41.

(iii) ***Step Turning*** – It is an operation of producing various steps of different diameters in the workpiece. It is shown in fig. 2.42.

(iv) ***Drilling*** – Drilling is the operation of producing a cylindrical hole in a workpiece by the rotating cutting edge of a cutter known as drill. In this, the workpiece is held in a chuck and the drill is held in the tailstock. The drill is fed manually, into the rotating workpiece, by rotating the tailstock hand wheel. Drilling is shown in fig. 2.43.

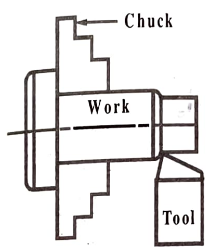


Fig. 2.41 Plain Turning

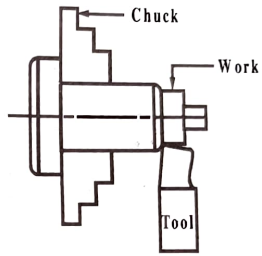


Fig. 2.42 Step Turning

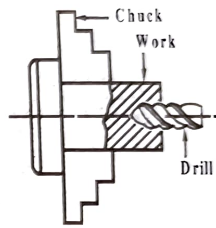


Fig. 2.43 Drilling

(v) ***Reaming*** – It is an operation of finishing the previously drilled hole. In this, a reamer is held in the tailstock and it is fed into the hole. Reaming operation is shown in fig. 2.44.

(vi) ***Boring*** – Boring is the operation of enlarging a hole produced by drilling, punching etc. It is really internal turning. A workpiece containing a drilled hole is rotated while the cutting tool moves in a straight line. It is shown in fig. 2.45.

(vii) ***Undercutting or Grooving*** – It is the process of reducing the diameter of a workpiece over a very narrow surface. In this, a tool of appropriate shape is fed into the revolving work upto the desired depth at right angles to the centre line of the workpiece. It is shown in fig. 2.46.

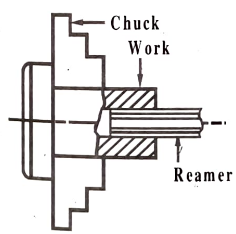


Fig. 2.44 Reaming

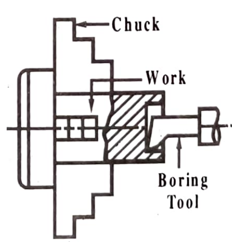


Fig. 2.45 Boring

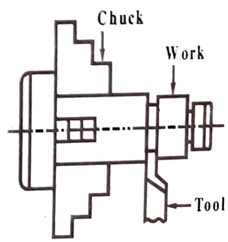


Fig. 2.46 Grooving

(viii) Threading – The process of cutting helical grooves on the external cylindrical surface of workpiece is called threading. In this, the work is held in a chuck or between centres and the threading tool is fed longitudinally to the revolving work. The longitudinal feed is equal to the pitch of the thread to be cut. It is shown in fig. 2.47.

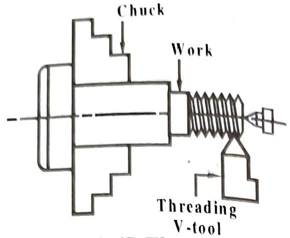


Fig. 2.47 Threading

(ix) Knurling – Knurling is the process of embossing a diamond shaped pattern on the surface of a workpiece. The purpose of knurling is to provide an effective gripping surface on a workpiece to prevent it from slipping.

In this operation, a knurled tool is moved longitudinally to a revolving workpiece surface. The projection on the knurled tool reproduces depressions on the work surface. It is shown in fig. 2.48.

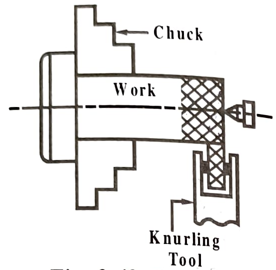


Fig. 2.48 Knurling

Q.88. Name and explain five operations which can be performed on a lathe machine. ***(R.G.P.V., June 2012)***

Ans. Refer Q.87.

Q.89. Draw a simple diagram of lathe machine and discuss any five operations, that can be performed on it. ***(R.G.P.V., Dec. 2010)***

Ans. Refer Q.85 and Q.87.

Q.90. Give types of lathe. Name the various operations which can be performed on a lathe machine. What are the advantages of using a taper turning attachment ? ***(R.G.P.V., Dec. 2013)***

***Ans.* Types of Lathe** – Refer Q.84.

Operations Performed on Lathe Machine – Refer Q.87.

Advantages of Using a Taper Turning Attachment – A taper turning attachment as shown in fig. 2.49. is used on a centre lathe for producing taper on a workpiece.

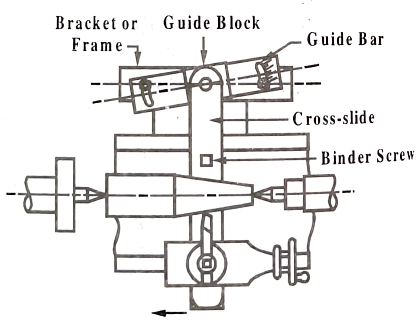


Fig. 2.49 Taper Turning Attachment

This attachment is confined to give external tapers only. It is bolted on the back of the lathe and has a guide bar which may be set at the desired angle of taper. As the carriage moves along the bed length, a slide over the bar causes the tool to move in and out according to the setting of the bar. The main advantage of this system is that the lathe centres are kept in alignment, and the same taper may be turned on various pieces, even though they vary in length.

Q.91. What is a drilling machine ? Discuss its working principle.

Ans. The process of originating or enlarging a hole in a solid member is termed as drilling.

A machine which can quickly drill holes at a low cost is called a drilling machine. The hole is generated by the rotating edge of a cutting tool known as the drill which exerts large force on the work clamped on the table. As the machine tool exerts vertical pressure to originate a hole it is sometimes called a "drill press".

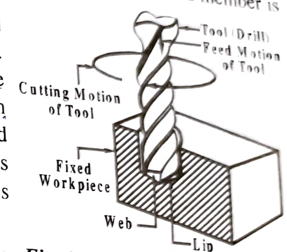


Fig. 2.50 Working Principle of a Drilling Machine

Working principle of a drilling machine is shown in fig. 2.50.

In order to cut off chips, two motions are given to the drill simultaneously, viz. rotary motion and linear motion. The rotary motion is the principal motion or cutting motion. In some cases, this rotary motion is given to workpieces also. The cutting motion is generally measured in m/min. The maximum cutting speed is on the periphery of the drill and it decreases towards the centre of the drill.

The linear motion is known as feed and it controls the thickness of the chip. The feed is generally measured in mm/rev. Since the drill is provided with two cutting edges, therefore, the thickness of the chip is half the feed.

Q.92. Name various types of drilling machines.

Ans. Drilling machines can be broadly classified in the following categories –

(i) Portable drilling machine
(ii) Sensitive drilling machine
  (a) Bench mounting (b) Floor mounting.
(iii) Upright drilling machine
  (a) Round column section (b) Box column section.
(iv) Radial drilling machine
  (a) Plain (b) Semi-universal (c) Universal.
(v) Gang drilling machine
(vi) Multiple spindle drilling machine
(vii) Automatic drilling machine
(viii) Deep hole drilling machine
  (a) Vertical (b) Horizontal.

Q.93. Explain sensitive drilling machine with the help of a neat sketch.

Ans. The block diagram of a sensitive drilling machine is shown in fig. 2.51. A sensitive or bench drilling machine is a small machine designed for drilling small holes at high speed in light jobs. Machines of this type are usually hand fed and operate on the principle of rack and pinion drive.

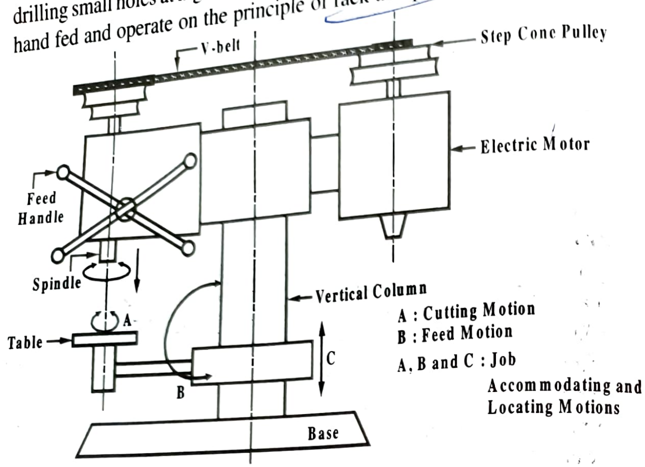


Fig. 2.51 Sensitive Drilling Machine

Constructional Details – It consists of a vertical column which carries a swivelling table, a head supporting the motor and driving mechanism and a vertical spindle for driving and rotating the drill. The driving mechanism consists of an endless belt running over two V-pulleys. One pulley is mounted on the motor shaft and the other on machine spindle. There is no gears in the drive. The drill is fed into the work by purely hand control. High speeds are necessary to attain required cutting speed by small diameter drill. Hand feed permits the operator to sense the progress of the drill into work. As the operator senses the cutting action, at any instant, it is called sensitive drilling machine. These machines are capable of rotating drills of diameter from 1.5 to 15.5 mm. This machine is rotated at high speed of 20,000 r.p.m.

Q.94. Explain the working of a vertical drilling machine with the help of a neat sketch. Also state the parameters used to specify a drilling machine.
(R.G.P.V., Dec. 2011)

Ans. **Vertical Drilling Machine –** A vertical or upright drilling machine as shown in fig. 2.52 is used for handling medium sized workpiece. In construction the machine is very similar to a sensitive drilling machine for having a vertical column mounted upon the base. But this is larger and heavier than a sensitive drill and is supplied with power feed arrangement. In an upright

drilling machine a large number of spindle speeds and feed may be available for drilling different types of work. The table of the machine also have different types of adjustments. There are two general classes of upright drilling machine –

(i) Round column section or pillar drilling machine.

(ii) Box column section drilling machine.

(i) Round Column Section or Pillar Drilling Machine – In pillar drilling machine, the table instead of being carried on vertical slides is carried on the round pillar. This helps in swinging the table to one side so that tall workpieces can be mounted on the base. Here, the table support is less rigid than the upright machine and places a restriction on its width. A box-column machine being more rigid than a round column machine, is adopted for heavier work.

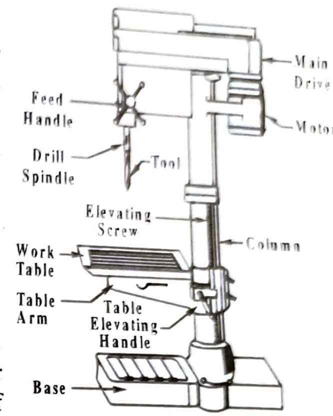


Fig. 2.52

(ii) Box Column Section or Column Drilling Machine – The column is of the box section. The box column is bolted to the base. The work table is incorporated with a bracket which slides on ways at the front of the machine. Support and elevating movement of the table is provided by a telescopic screw underneath its centre. The table on these machines can be swung.

Parameters to Specify a Drilling Machine – A heavy duty drilling machine is specified by following parameters –

(i) Drilling capacity
(ii) Taper in spindle (Morse number)
(iii) Distance between column and spindle, in case of radial drilling machine
(iv) Transverse of spindle
(v) Minimum distance between spindle and table
(vi) Minimum distance between spindle and base plate
(vii) Working surface of table (i.e., diameter)
(viii) Range of spindle speeds
(ix) Range of power feed per revolution
(x) Motor power
(xi) Motor speed.

Q.95. Explain the various drilling operations done by drilling machine.
(R.G.P.V., June 2010)

Ans. Various operations that can be performed on a drilling machine are given as follows –

(i) Drilling (ii) Spot facing (iii) Reaming
(iv) Tapping (v) Boring (vi) Lapping
(vii) Counterboring (viii)Grinding (ix) Countersinking
(x) Trepanning.

(i) Drilling – It is the operation of generating a cylindrical hole by removing metal by the rotating edge of a cutting tool known as drill. The drilling is one of the simplest method of producing a hole. Before drilling the centre of the hole to be produced is located on the workpiece by drawing two lines at right angles to each other and then a centre punch is used to generate an indentation at the centre. The drill point is pressed at this centre point to generate the required hole. This process does not produce an accurate hole and the hole so generated becomes rough and the hole is always slightly oversize than the drill used due to the vibration of the spindle and the drill. Fig. 2.53 illustrates a drilling operation.

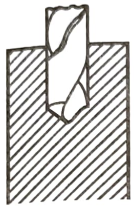


Fig. 2.53 Drilling

(ii) Spot Facing – This is an operation of smoothing and squaring the surface around a hole for the seat of a nut or the head of a screw. A counterbore may be employed for this purpose. Spot facing is shown in fig. 2.54.

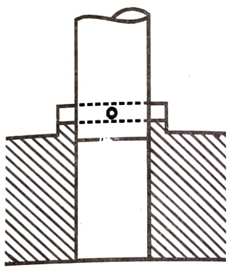


Fig. 2.54 Spot Facing

(iii) Reaming – It is an operation of slightly enlarging a previously drilled hole to proper size with a smooth finish. In order to finish a hole and to bring it to the accurate size, the hole is drilled slightly undersize. The spindle speed is made half that of drilling and automatic feed may be used. The tool used for reaming is called reamer. Reamer cannot originate a hole. It simply follows the path and removes a very small amount of metal. The reamer has multiple cutting edges.

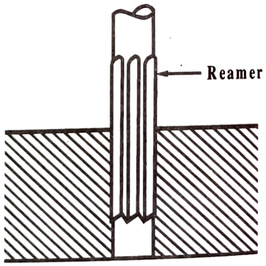


Fig. 2.55 Reaming

The material removed by reaming is around 0.375 mm and for accurate work this should not exceed 0.125 mm. Reaming process is shown in fig. 2.55.

(iv) Tapping – It is an operation of producing internal threads in a hole by means of a tool known as tap. A tap may be considered as a bolt with accurate threads cut on it. The threads act as cutting edges which are hardened

and ground. When the tap is screwed into the previously drilled hole it removes metal and cuts internal threads which will fit into external threads of the same dimensions. It is evident that the drilled hole must be smaller than the tap by twice the depth of the thread. Tapping is shown in fig. 2.56.

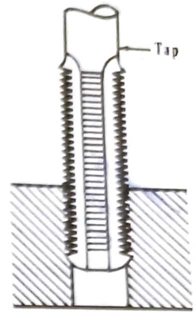


Fig. 2.56 Tapping

(v) Boring – Boring is performed on a drilling machine for the following purposes –

(a) To machine the internal surface of a hole already produced in casting.

(b) To enlarge a hole by means of an adjustable cutting tool with only one cutting edge.

(c) To correct the location of the hole as the boring tool follows an independent path with respect to the hole.

(d) To finish a hole accurately and to bring it to the required size.

(e) To correct out of roundness of the hole.

Boring operation is shown in fig. 2.57.

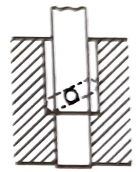


Fig. 2.57 Boring

(vi) Lapping – It is the operation of sizing and finishing a small diameter hole already drilled by removing a very small amount of material by using a lap. There are various types of lapping tools. The copper head laps are commonly used. The lap is moved up and down in a hole while it revolves.

(vii) Counterboring – Counterboring is shown in fig. 2.58.

Counterboring is the operation of enlarging the end of a hole cylindrically. The enlarged hole forms a square shoulder with the original hole. This is necessary in some cases to accommodate the heads of pins, studs or bolts. The tool used for counterboring is known as counterbore. The counterbore is made with straight or tapered shank to fit in the drill spindle. The cutting edges may have straight or spiral teeth. The tool is guided by a pilot which extends beyond the end of the cutting edges. The pilot fits into the previously drilled hole having running clearance and maintains the alignment of the tool. These pilots may be interchanged for enlarging different size of holes.

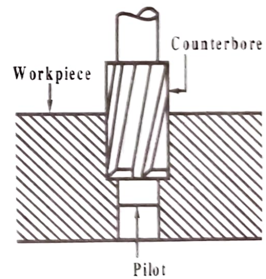


Fig. 2.58 Counterboring

(viii) Countersinking – Countersinking is shown in fig. 2.59.

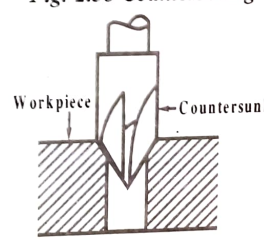


Fig. 2.59 Countersinking

Countersinking is the process of making a cone-shaped enlargement at the end of a hole to provide a recess for a countersunk rivet or flat head screw. The tool used for countersinking is known as countersunk. Standard countersunks have 60°, 82° or 90° included angle. Cutting edges of the tool are formed at the conical surface. In countersinking, the cutting speed is 25% less than that of drilling.

Q.96. Write brief about drilling machine –
(i) Sketch (ii) Types of drilling machines
(iii) Operations performed. ***(R.G.P.V., June 2016)***

Ans. (i) *Sketch* – Refer Q.94.

(ii) *Types of Drilling Machines* – Refer Q.92.

(iii) *Operations Performed* – Refer Q.95.

Q.97. Draw a neat sketch of radial drilling machine, discuss its various operations. ***(R.G.P.V., Dec. 2010)***

Or

Discuss any three operations that can be performed on a radial drilling machine. Also draw a labelled diagram of a radial drilling machine. ***(R.G.P.V., June 2011)***

Ans. A radial drilling machine is shown in fig. 2.60.

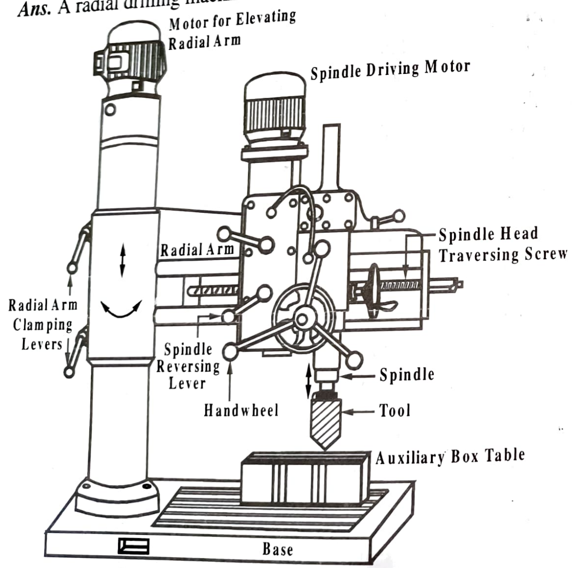


Fig. 2.60 Radial Drilling Machine

For various drilling operations, refer Q.95.

UNIT 3

FLUIDS

FLUID PROPERTIES – PRESSURE, DENSITY AND VISCOSITY, ETC.

Q.1. Define fluid and fluid mechanics.

Ans. **Fluid –** A fluid may be defined as a substance which is capable of flowing. It has no definite shape of its own, it can take the shape of vessel containing it. The fluid particles readily change their relative positions. Even a shear stress of negligible magnitude can cause the deformation in the fluid. All liquids and gases are termed as fluids.

Fluid Mechanics – Fluid mechanics is a physical science, which deals with the behaviour of fluids at rest or in motion. Thus fluid mechanics deals with static, kinematic and dynamic behaviour of fluids. The study of fluids at rest is called fluid statics. The study of fluids in motion, when pressure forces are not considered, is called fluid kinematics (or kinetics) and if pressure forces are also considered, the study is called fluid dynamics.

Q.2. Name various properties of fluids and define any one of them.

Ans. Some of the important properties of fluids are –

(i) Density	(ii) Specific weight
(iii) Specific volume	(iv) Specific gravity
(v) Viscosity	(vi) Kinematic viscosity
(vii) Compressibility	(viii) Vapour pressure
(ix) Cohesion and adhesion	(x) Surface tension
(xi) Capillarity.	

Specific Weight – Specific weight or weight density of a fluid may be defined as the weight per unit volume. It is represented by w. Mathematically,

$$\text{Specific weight,} \quad w = \frac{\text{Weight}}{\text{Volume}}$$

Specific weight of water for all practical purposes may be taken as 9.81 kN/m^3.

Variation of specific weight with pressure or temperature is also negligible.

Q.3. Define pressure and give its units.

Ans. Pressure or intensity of pressure may be defined as the force exerted on a unit area. Whenever a fluid (liquid or gas) is stored in a vessel, it exerts force at all points on the sides and bottom of the container. This force is not uniformly distributed over the entire surface area. If dF be the force on a unit area dA then intensity of pressure or simply pressure can be given as

$$\text{Pressure,} \qquad p = \frac{dF}{dA}$$

If the force F is uniformly distributed over area A, then pressure at any point will be given by

$$p = \frac{F}{A}$$

The units of pressure are N/m^2 or N/mm^2 in S.I. units and kgf/cm^2 in M.K.S. units. 1 N/m^2 is known as Pascal and represented by Pa. Another common unit of pressure is bar, where

$$1 \text{ bar} = 10^5 \text{ N/m}^2 = 100 \text{ kPa}$$

Q.4. What do you mean by vacuum pressure ? ***(R.G.P.V., June 2014)***

Ans. When pressure falls below the atmospheric pressure, it is termed as vacuum pressure. A vacuum gauge is used to measure vacuum pressure. Mathematically, vacuum pressure is given as

$$p_{vacuum} = p_{atmospheric} - p_{absolute}$$

Q.5. Differentiate between absolute pressure and gauge pressure. How can we measure pressure exerted by fluid ? ***(R.G.P.V., June 2012)***

Ans. Fluid pressure may be measured with respect to any arbitrary datum. The two most common datums are –

(i) Local atmospheric pressure (ii) Absolute zero pressure.

On the basis of datum chosen, pressure may be –

(i) Gauge Pressure – Pressure which is measured with reference to the atmospheric pressure is termed as gauge pressure. It is measured with the help of a pressure measuring instrument. The atmospheric pressure on gauge scale is marked as zero. Generally, this is measured above the atmospheric pressure.

(ii) Absolute Pressure – The pressure which is measured with reference to the absolute zero or complete vacuum is termed as absolute pressure. Absolute pressure is the algebraic sum of atmospheric and gauge (or vacuum) pressure.

Mathematically,

$$p_{absolute} = p_{atmospheric} + p_{gauge}$$

or

$$p_{absolute} = p_{atmospheric} - p_{vacuum}$$

Relative position of these pressures is shown in fig. 3.1.

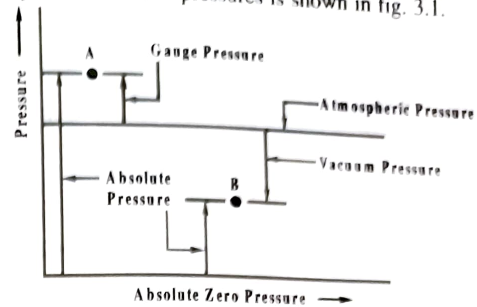


Fig. 3.1

Pressure Measurement – The pressure exerted by a fluid can be measured by means of U-tube manometer, which is discussed in Unit-II, Q.19.

Q.6. What do you mean by fluid ? Define any three properties of fluid. ***(R.G.P.V., June 2016)***

***Ans.* Fluid** – Refer Q.1.

Three properties of fluid are defined below –

(i) Density – Density or mass density of a fluid may be defined as the mass per unit volume. It is denoted by symbol ρ (rho) and in S.I. units it is expressed in kg/m^3. Mathematically,

$$\text{Density,} \qquad \rho = \frac{\text{Mass}}{\text{Volume}}$$

The density of water at 4°C at mean sea level is 1000 kg/m^3.

The density of fluid increases with increase in pressure and decreases with increase in temperature. However, that variation is so small, it can be neglected.

(ii) Specific Volume – It is the volume occupied by a unit weight or unit mass of the fluid. It is commonly applied to gases and is usually expressed in cubic metre per Newton or cubic metre per kilogram.

It is the reciprocal of mass density. It is denoted by v_s.

Mathematically,

$$\text{Specific volume,} \qquad v_s = \frac{\text{Volume}}{\text{Mass}} = \frac{1}{\text{Density}} = \frac{1}{\rho}$$

(iii) Specific Gravity – The specific gravity of a fluid is the ratio of its weight density (or specific weight) to that of a standard fluid, both being referred to standard conditions of temperature and pressure.

For liquids, pure water is taken as a standard substance at 4°C and for gases either air free of CO_2 or hydrogen at 0°C is taken.

Specific gravity (SG) of water is one and that of the mercury is 13.5 to 13.6.

Specific gravity of liquid,

$$SG = \frac{\text{Specific weight of liquid}}{\text{Specific weight of water}}$$

Being ratio of same property, it is an unitless quantity.

Q.7. Discuss in short following properties related to fluids – Pressure, viscosity, density **(R.G.P.V., June 2011)**

Ans. **Pressure** – Refer Q.3.

Viscosity – Viscosity of a fluid is a property by virtue of which it offers resistance to the movement of one layer of fluid over another adjacent layer. When two layers of fluid, a distance dy apart move one over the other at different velocities say v and v + dv as shown in fig. 3.2, the viscosity together relative velocity causes a shear stress between the layers of fluid. This is mainly due to cohesion and molecular momentum exchange between fluid layers.

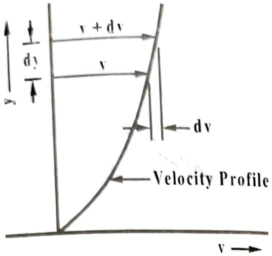


Fig. 3.2

The shear stress between two adjacent fluid layers is proportional to the rate of change of velocity with respect to y. Hence

$$\text{Shear stress,} \quad \boxed{\tau \propto \frac{dv}{dy} \text{ or } \tau = \mu\frac{dv}{dy}} \qquad ...(i)$$

where μ is the constant of proportionality which is known as ***coefficient of viscosity*** or ***dynamic viscosity*** or simply ***viscosity***.

Euation (i) can also be written as

$$\mu = \frac{\tau}{dv/dy}$$

Thus, dynamic viscosity (or viscosity) is the shear stress required to produce unit shear strain or unit average deformation.

Density – Refer Q.6, section (i).

Q.8. Define kinematic viscosity of fluid. What is its unit of measurement ? **(R.G.P.V., Dec. 2014)**

Ans. Kinematic viscosity may be defined as the ratio of dynamic viscosity (μ) and mass density (ρ). It is denoted by symbol ν (called nu). Mathematically,

$$\text{Kinematic viscosity,} \quad \nu = \frac{\text{Dynamic viscosity, } \mu}{\text{Mass density, } \rho}$$

The unit of ν in C.G.S., is cm^2/sec and it is called the stoke and in M.K.S. and S.I. units, it is expressed as m^2/s.

$$\text{One stoke} = cm^2/sec = \left(\frac{1}{100}\right)^2 m^2/s = 10^{-4} m^2/s$$

Q.9. What is the difference between the dynamic viscosity and kinematic viscosity ? **(R.G.P.V., Dec. 2017)**

Ans. Refer Q.7 and Q.8.

NUMERICAL PROBLEMS

Prob.1. Calculate specific weight, density, specific volume and specific gravity of petrol, if one litre of petrol weighs 6.867 N. **(R.G.P.V., June 2014)**

Sol. Given, $V = 1 \text{ litre} = 1 \times 10^{-3} m^3$, $W = 6.867$ N.

$$\text{Specific weight,} \quad w = \frac{\text{Weight (W)}}{\text{Volume (V)}}$$

$$= \frac{6.867}{1 \times 10^{-3}} = \mathbf{6867\ N/m^3} \qquad \textbf{Ans.}$$

$$\text{Density,} \quad \rho = \frac{w}{g} = \frac{6867}{9.81} = \mathbf{700\ kg/m^3} \qquad \textbf{Ans.}$$

$$\text{Specific volume,} \quad v_s = \frac{1}{\text{Density}}$$

$$= \frac{1}{\rho} = \frac{1}{700} = \mathbf{1.4286 \times 10^{-3}\ m^3/kg} \qquad \textbf{Ans.}$$

Specific gravity (or relative density),

$$S = \frac{\text{Density of petrol}}{\text{Density of water}} = \frac{700}{1000} = 0.7 \qquad \textbf{Ans.}$$

Prob.2. If 5 m^3 of a certain oil weighs 40 kN, calculate the specific weight, mass density and relative density of the oil. **(R.G.P.V., June 2010)**

Sol. This problem can be solved in a similar way as discussed in prob.1.

Prob.3. The velocity distribution of flow over a flat plate is given by $u = \frac{1}{3}y^2 - \frac{1}{4}y$, where u is the velocity of water in m/s, at a distance y m above the plate. Determine the shear stress at a distance 1.8 m above the plate. **(R.G.P.V., Dec. 2011)**

Sol. Let dynamic viscosity of fluid

$$\mu = 10 \text{ poise} = 1 \text{ N-s/m}^2$$

Velocity distribution is given by,

$$u = \frac{1}{3}y^2 - \frac{1}{4}y$$

$\therefore$ Velocity gradient. $\frac{du}{dy} = \frac{2}{3}y - \frac{1}{4}$

and shear stress. $\tau = \mu \frac{du}{dy}$

We know that. At y = 1.8 m (given)

$$\left(\frac{du}{dy}\right)_{1.8} = \frac{2}{3} \times 1.8 - \frac{1}{4} = 0.95/s$$

$\therefore$ $(\tau)_{1.8} = 1 \times 0.95 = \mathbf{0.95\ N/m^2}$ **Ans.**

TYPES OF FLUIDS, NEWTON'S LAW OF VISCOSITY, PASCAL'S LAW, BERNOULLI'S EQUATION FOR INCOMPRESSIBLE FLUIDS

Q.10. How fluids are classified ? ***(R.G.P.V., June 2015)***

Or

Differentiate between real fluid and ideal fluid. ***(R.G.P.V., Dec. 2014)***

Ans. Fluids can be broadly classified as

(i) Ideal fluid (ii) Real fluid.

(i) Ideal Fluid – Ideal fluid is a fluid which is incompressible and inviscid. A fluid for which density (ρ) remains constant is called incompressible fluid. A fluid for which viscosity (μ) is zero, is called inviscid fluid. Hence a fluid for which density is constant and viscosity is zero is known as ideal fluid. For an ideal fluid surface tension (σ) is also zero.

Since, shear stress is given by $\tau = \mu \frac{du}{dy}$ and for ideal fluid flow μ is zero, thus there will be no shear stress or shear force in case of ideal (or potential flow). The ideal fluids thus will be moving with uniform velocity.

Ideal fluids are imaginary and do not exist in nature. However, fluids such as water and air having very low viscosity can be treated as ideal fluids. Water being incompressible is more near to an ideal fluid than air.

(ii) Real Fluid – Real or practical fluids are those fluids which are actually available in nature. These fluids possess the properties such as viscosity, surface tension and compressibility and therefore a certain amount of resistance is always offered by these fluids when they are set in motion.

Q.11. State the Newton's law of viscosity and give examples of its application. ***(R.G.P.V., June 2014)***

Or

Write the Newton's law of viscosity. ***(R.G.P.V., Dec. 2016)***

Or

State Newton's law of viscosity.

(R.G.P.V., March/April 2010, Dec. 2011, June 2015, Dec. 2017)

Ans. Newton's law of viscosity states that the shear stress on a fluid layer is directly proportional to the rate of shear strain. Mathematically,

Shear stress, $\tau \propto \frac{dv}{dy}$ or $\tau = \mu \frac{dv}{dy}$

Newton's law of viscosity is found to be useful in –

(i) Classifying the fluids.

(ii) Determining response of a fluid to a shearing stress.

(iii) Understanding various fluid phenomena.

Q.12. State Newton's law of viscosity. What is the effect of temperature on viscosity of water and gas ? ***(R.G.P.V., June 2012)***

Ans. **Newton's Law of Viscosity** – Refer Q.11.

Effect of Temperature on Viscosity – Viscosity of a fluid is a measure of internal fluid friction, which causes resistance to flow. This friction is mainly due to cohesive forces of fluid particles and molecular momentum exchange. These forces depends upon the temperature, thus viscosity of a fluid is a function of temperature. The viscosity of liquids decreases with the increase of temperature, while the viscosity of gases increases with the increase of temperature. This is because, in liquids molecules are closely packed and cohesive forces predominates molecular momentum exchange, when temperature is increased, the cohesive forces decreases and thus decreases the viscosity. But in case of gases, molecules are far distant, thus molecular momentum transfer predominates over cohesive forces. On increasing the temperature molecular momentum transfer increases and thus increases their viscosity. The relation between viscosity and temperature of liquids and gases are given below –

(i) For liquids, $\mu = \mu_0\left(\frac{1}{1+\alpha t+\beta t^2}\right)$

where, μ = Viscosity of liquid at t°C

μ_0 = Viscosity of liquid at 0°C

α and β = Constants.

For water, $\mu_0 = 1.79 \times 10^{-3}$ poise, $\alpha = 0.03368$, $\beta = 0.000221$.

(ii) For gases, $\mu = \mu_0 + \alpha t - \beta t^2$

For air, $\mu_0 = 0.000017$ poise, $\alpha = 56 \times 10^{-9}$, $\beta = 1.189 \times 10^{-9}$.

Q.13. Define fluid statics.

Ans. Fluid statics is the study of fluid at rest. The fluid either may be actually at rest or it may undergo uniform acceleration, so that there is no relative motion between the fluid elements. Thus, there is no velocity grdient

$\left(\frac{dv}{dy}=0\right)$ and hence no shear stress can exist whatever may be the viscosity of the fluid. Since viscosity has no effect, real fluids can be treated as ideal fluids for solving the problems.

Q.14. What is hydrostatic law ? Explain it. **(R.G.P.V., Dec. 2014)**

Ans. The pressure in a fluid does not remain constant, even if the fluid is at rest. The pressure varies in vertical direction or with the depth, and rate of increase of pressure is equal to the weight density of fluid at that point. This is known as ***hydrostatic law***. The pressure variation at any point in a fluid at rest can be obtained by hydrostatic law.

According to hydrostatic law,

$$\frac{\partial p}{\partial z} = -w = -\rho g$$

or

$$\partial p = (-\rho g)\partial z \quad ....(i)$$

–ve sign indicates that the pressure decreases in the direction in which z increases, i.e. in the upward direction.

In equation (i), if $\partial z = 0$, then $\partial p = 0$, i.e. the pressure will remain constant everywhere over the same level surface in a continuous body of static fluid.

Q.15. What do you understand by the term kinetic energy ? **(R.G.P.V., Dec. 2016)**

Ans. Kinetic energy is the energy possessed by a fluid body by virtue of its motion.

According to Newton's second law of motion,

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$dF = m\frac{dv}{dt}$$

Multiplying both sides by ds, the differential displacement of both force and fluid mass, we get

$$dF \times ds = m\,dv\frac{ds}{dt}$$

or

$$d\,(W.D.) = m\,v\,dv \qquad \left(\because \frac{ds}{dt} = v\right)$$

If the fluid mass accelerates from velocity v_1 to v_2, then

$$\int d(W.D.) = m\int v\,dv$$

or

$$W.D. = \frac{1}{2}m(v_2^2 - v_1^2)$$

Work required to accelerate the fluid mass from rest to a velocity v is called kinetic energy, thus,

$$\text{Kinetic energy (K.E.)} = \frac{1}{2}mv^2 = \frac{1}{2}\frac{W}{g}v^2$$

where, W = mg = Weight of the fluid body in Newton.

Q.16. Define the terms –

(i) Viscosity *(ii) Pressure*
(iii) Kinetic energy *(iv) Datum energy*
(v) Compressible fluid.

Ans. **(i) Viscosity** – Refer Q.7. **(R.G.P.V., Dec. 2013)**

(ii) Pressure – Refer Q.3.

(iii) Kinetic Energy – Refer Q.15.

(iv) Datum Energy – Datum energy or potential energy is the energy possessed by a fluid body by virtue of its position or location with respect to some arbitrary horizontal plane.

The datum energy actually represents the work required to move the fluid body against the gravitational pull of the earth, from a reference elevation to a position Z metre above or below the reference elevation/datum plane. The datum energy of W Newton of a fluid body at a height Z metre above the datum plane will be

$$= WZ = mgZ$$

(v) Compressible Fluid – A fluid having variable density is called a compressible fluid. A compressible fluid contracts when a pressure is applied to it, and expands when pressure is released. The coefficient of compressibility of a fluid is given as

$$\beta = -\frac{dV/V}{dp}$$

where dV is the incremental volume change in the original volume V, when subjected to a small change in pressure dp. The negative sign implies that the volume of fluid decreases with the increase in the pressure.

Generally, the compressibility of a fluid is expressed by bulk modulus of elasticity (K), which is the inverse of the coefficient of compressibility, i.e.

$$K = \frac{1}{\beta} = -\frac{dp}{dV/V}$$

Q.17. State and prove Pascal's law of fluid pressure.

Ans. Pascal's law states that the pressure (or intensity of pressure) at any point in a fluid at rest is equal in all directions. In other words a pressure applied at any point in a fluid at rest is equally transmitted in all the directions and to every other point in the fluid.

Consider an arbitrary wedge shaped element of fluid at rest as shown in fig. 3.3. Let the width of the element be unity and p_x, p_y and p_z be the intensities of pressure acting on the faces AB, AC and BC respectively. Also let θ is the angle of wedge shaped element of liquid.

As fluid is at rest, therefore there will be no shear stress, the only forces acting on the element are the pressure forces normal to the surface and self weight of element in vertical direction.

Now, pressure force on face AB

$= p_x.\text{Area of face AB}$

$= p_x.\ dy.\ 1 = p_x.dy$

Similary pressure force on face AC

$= p_y.dx$

and pressure force on face BC $= p_z.ds$

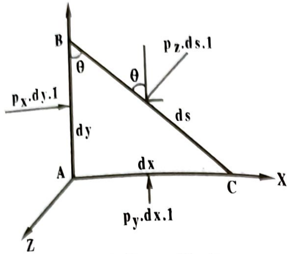


Fig. 3.3 Pascal's Law

Weight of the liquid element = W (let)

Now for equilibrium of the fluid element resolving the forces horizontally,

$$p_x\ dy - (p_z.ds)\sin(90-\theta) = 0$$

$$p_x\ dy - p_z\ ds\cos\theta = 0$$

But from geometry of fig. 3.3, $ds\cos\theta = dy$

$$\therefore \quad p_x\ dy - p_z\ dy = 0$$

or $$p_x = p_z \quad \text{....(i)}$$

Again resolving the forces vertically,

$$p_y.dx - p_z ds.\cos(90-\theta) - W = 0$$

$$p_y.dx - p_z\ ds\sin\theta - W = 0$$

But from geometry of fig. 3.3, $ds\sin\theta = dx$ and also the element is very small and hence its weight is negligible.

$$\therefore \quad p_y.dx - p_z dx = 0$$

or $$p_y = p_z \quad \text{....(ii)}$$

From equations (i) and (ii), we have

$$p_x = p_y = p_z$$

Thus, pressure at any point in a fluid, at rest, is same in all directions.

Q.18. State Bernoulli's equation for incompressible fluids.

(R.G.P.V., June 2016)

Ans. Bernoulli's theorem states, "For a perfect incompressible liquid, flowing in a continuous stream, the total energy of a particle remains constant; while the particle moves from one point to another." This statement is based on the assumption that there are no losses due to friction in the pipe. Mathematically,

$$\boxed{\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant}}$$

This is ***Bernoulli's equation*** in which

$\frac{p}{\rho g}$ = Pressure energy per unit weight of fluid or pressure head

$\frac{v^2}{2g}$ = Kinetic energy per unit weight or kinetic head

z = Potential energy per unit weight or potential head.

Q.19. What are the applications of Bernoulli's theorem ?

(R.G.P.V., June 2015)

Ans. Bernoulli's equation is the basic equation of fluid mechanics. Bernoulli's equation can be applied to all problems of incompressible fluid where energy considerations are involved. Though it may have number of practical applications, but some important applications are to the following measuring devices –

(i) Pitot tube (ii) Venturimeter (iii) Orifice meter
(iv) Nozzle meter (v) Rotameter.

Q.20. Establish the Bernoulli's theorem from the Euler equation of motion through a stream tube.

(R.G.P.V., Dec. 2012)

Ans. Bernoulli's equation relates velocity, pressure and elevation changes of a fluid in motion. The equation can be obtained by integrating the Euler's equation along the streamline for a constant density (incompressible fluid). Euler's equation of motion through a stream tube is given by,

$$\frac{dp}{\rho} + g dz + v dv = 0$$

Integrating above equation on both sides,

$$\int \frac{dp}{\rho} + \int g.dz + \int v.dv = \text{Constant}$$

If flow is incompressible, ρ is constant.

$$\therefore \quad \frac{p}{\rho} + gz + \frac{v^2}{2} = \text{Constant} \quad \text{or} \quad \frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{Constant}$$

This is ***Bernoulli's equation*** in which

$\frac{p}{\rho g}$ = Pressure head

$\frac{v^2}{2g}$ = Kinetic head and z = Potential head.

Q.21. State Bernoulli's theorem and derive equation for the flow of an incompressible fluid. Mention the assumptions made for deriving it.

(R.G.P.V., June 2014)

Or

What is Bernoulli's theorem for incompressible fluid ? How is it used to measure flow in a pipe ? **(R.G.P.V., June 2013)**

Or

State and prove Bernoulli's equation for incompressible fluids. State its assumptions. **(R.G.P.V., Dec. 2010)**

Ans. **Statement of Bernoulli's Theorem** – Refer Q.18.

Proof – Consider a perfect (non-viscous), incompressible liquid flowing through a non-uniform pipe as shown in fig. 3.4.

Let us consider two sections A-A and B-B of the pipe. Now, let us assume that the pipe is running full and there is a continuity of flow between the two sections.

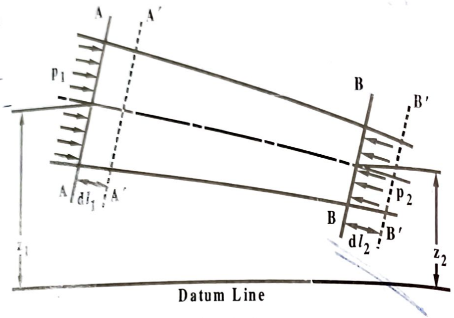


Fig. 3.4

Let. z_1 = Height of A-A above the datum

p_1 = Pressure at A-A

v_1 = Velocity of liquid at A-A

A_1 = Area of the pipe at A-A

z_2, p_2, v_2, A_2 = Corresponding values at B-B.

Let the liquid between the two sections A-A and B-B move to A'-A' and B'-B' through very small lengths dl_1 and dl_2 in an infinitely small interval of time. This movement of the liquid between A-A and B-B is equivalent to the movement of the liquid between A-A and A'-A' to B-B and B'-B', the remaining liquid between A'-A' and B-B being unaffected.

Let W be the weight of the liquid between A-A and A'-A' since the flow is continuous, therefore,

$$W = w.a_1 dl_1 = w.a_2.dl_2$$

where w = Specific weight of the liquid.

or
$$a_1 dl_1 = \frac{W}{w} \quad \text{....(i)}$$

Similarly
$$a_2 dl_2 = \frac{W}{w}$$

$$\therefore \quad a_1 dl_1 = a_2 dl_2 \quad \text{....(ii)}$$

Workdone by pressure at A-A, in moving the liquid to A'-A'

$$= \text{Force} \times \text{Distance} = p_1 a_1.dl_1$$

Similarly workdone by pressure at B-B in moving the liquid to B'-B'

$$= -p_2 a_2.dl_2$$

Minus sign is taken because the direction of p_2 is opposite to that of p_1.

$\therefore$ Total workdone by the pressure

$$= p_1 a_1.dl_1 - p_2 a_2.dl_2$$

$$= p_1 a_1.dl_1 - p_2 a_1.dl_1 \quad (\because a_1 dl_1 = a_2.dl_2)$$

$$= a_1 dl_1 (p_1 - p_2) = \frac{W}{w}(p_1 - p_2) \quad \left(\because a_1 dl_1 = \frac{W}{w}\right)$$

Loss of potential energy = $W(z_1 - z_2)$ and gain in kinetic energy

$$= W\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right) = \frac{W}{2g}\left(v_2^2 - v_1^2\right)$$

According to law of conservation of energy,

Loss of potential energy + Workdone by pressure = Gain in kinetic energy

$$\therefore \quad W(z_1 - z_2) + \frac{W}{w}(p_1 - p_2) = \frac{W}{2g}\left(v_2^2 - v_1^2\right)$$

$$(z_1 - z_2) + \frac{p_1}{w} - \frac{p_2}{w} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

or
$$\frac{p_1}{w} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{w} + \frac{v_2^2}{2g} + z_2 \quad \text{...(iii)}$$

As sections A-A and B-B are chosen arbitrarily, therefore for any section,

$$\frac{p}{w} + \frac{v^2}{2g} + z = \text{Constant}$$

or
$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{Constant} \quad \text{...(iv)}$$

This is the required Bernoulli's equation.

Assumptions –

(i) Fluid is ideal i.e., viscosity is zero.

(ii) Flow is steady i.e., fluid properties at a given point does not vary with time.

(iii) Flow is incompressible i.e., no variation in fluid density.

(iv) Flow is essentially one dimensional i.e., along a streamline.

(v) Flow is continuous and velocity is uniform over a section.

(vi) Only gravity and pressure forces are present. No energy in he form of heat or work is either added or subtracted from the fluid.

These assumptions are rarely possible in actual practice. In case of a real incompressible fluid flowing steadily there is some loss of useful energy due to viscous and turbulent friction. Thus, if h_L is the loss of energy per unit weight of fluid between sections 1-1 and 2-2, equation (iii) may be modified as,

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2+h_L \quad \ldots(v)$$

Q.22. Derive Bernoulli's equation for a perfect incompressible liquid. ***(R.G.P.V., June 2015)***

Ans. Refer Q.21.

Q.23. Give limitations of Bernoulli's theorem.

Ans. The Bernoulli's theorem or Bernoulli's equation has been derived on certain assumptions, which are rarely possible in actual practice. Based on those assumptions Bernoulli's theorem has following limitations –

(i) The Bernoulli's equation has been derived under the assumption that the velocity of every liquid particle, across any cross-section of a pipe, is uniform. But in actual practice, it is not so. The velocity of liquid particle in the centre of a pipe is maximum and gradually decreases towards the walls of the pipe due to the pipe friction. Thus, while using Bernoulli's equation the mean velocity of liquid should be considered.

(ii) The Bernoulli's equation has been derived under the assumption, that no external force, except the gravity force is acting on the liquid. But in actual practice, it is not so, there are always some external forces, (such as pipe friction etc.) acting on the liquid, which effect the flow of the liquid. If some energy is supplied to, or extracted from the flow, the same should also be taken into account.

(iii) The Bernoulli's equation has been derived, under the assumption, that there is no loss of energy of the liquid particle while flowing. But in actual practice, it is rarely so. In a turbulent flow, some kinetic energy is converted into heat energy; and in a viscous flow some energy is lost due to shear forces.

(iv) For a liquid flowing in a curved path, the energy due to centrifugal force should also be taken into account, which is not so in the Bernoulli's equation.

NUMERICAL PROBLEMS

Prob.4. Water is flowing through a pipe having diameter 300 mm and 200 mm at the bottom and upper end respectively. The intensity of pressure at the bottom end is 24.525N/cm² and the pressure at the upper end is 9.81N/cm². Determine the difference in datum head if the rate of flow through pipe is 40 lit./s. ***(R.G.P.V., Dec. 2017)***

Sol. Given, D_1 = 300 mm = 0.3 m, D_2 = 200 mm = 0.2 m, p_1 = 24.525 N/cm² = 24.525 × 10^4 N/m², p_2 = 9.81 N/cm² = 9.81 × 10^4 N/m², Q = 40 lit/s = 0.04 m³/s.

The pipe arrangement used for water flow is shown in fig. 3.5.

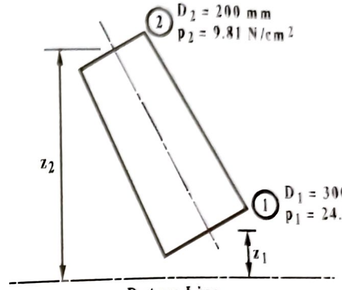


Fig. 3.5

From continuity equation, we have

$$Q = A_1 v_1 = A_2 v_2 \quad \ldots(i)$$

$$\therefore \quad v_1 = \frac{Q}{A_1} = \frac{0.04}{\frac{\pi}{4}\times(0.3)^2} = 0.5658 \text{ m/s}$$

and

$$v_2 = \frac{Q}{A_2} = \frac{0.04}{\frac{\pi}{4}\times(0.2)^2} = 1.2732 \text{ m/s}$$

Now applying Bernoulli's equation at sections 1 and 2, we get

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2$$

$$\frac{24.525\times10^4}{1000\times9.81}+\frac{(0.5658)^2}{2\times9.81}+z_1=\frac{9.81\times10^4}{1000\times9.81}+\frac{(1.2732)^2}{2\times9.81}+z_2$$

$$25 + 0.0163 + z_1 = 10 + 0.0826 + z_2$$

or

$$z_2 - z_1 = 14.9337 \simeq 14.93 \text{ m}$$

∴ Difference in datum head

$$= z_2 - z_1 = \mathbf{14.93 \ m} \quad \textbf{Ans.}$$

Prob.5. A pipe of 200 m has a slope of 1 in 100 and tapers from 1 m diameter at the high end to 0.4 m at the low end. Rate of water flow is 4000 l/min. If the pressure at the high end is 50 kPa, find the pressure at the low end. ***(R.G.P.V., Dec. 2016)***

Sol. Given, L = 200 m, Slope = 1 in 100, D_1 = 1 m, D_2 = 0.4 m, Q = 4000 litres/minute = $\frac{4000}{60 \times 1000}$ m³/s = 0.067 m³/s, p_1 = 50 kPa = 50×10^3 N/m².

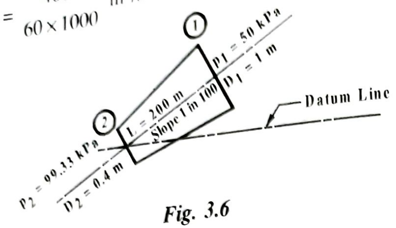


Fig. 3.6

Area at the high end,

$$A_1 = \frac{\pi}{4} \times D_1^2 = \frac{\pi}{4} \times 1^2 = 0.7854 \text{ m}^2$$

Area at the low end, $A_2 = \frac{\pi}{4} \times D_2^2 = \frac{\pi}{4} \times (0.4)^2 = 0.1257 \text{ m}^2$

Let, the datum line is passing through the centre of the lower end.

Then $\qquad z_2 = 0$

As slope is 1 in 100 thus

$$z_1 = \frac{1}{100} \times 200 = 2 \text{ m}$$

We know that, $\qquad Q = A_1 v_1 = A_2 v_2$

$$\therefore \quad v_1 = \frac{Q}{A_1} = \frac{0.067}{0.7854} = 0.0853 \text{ m/s}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.067}{0.1257} = 0.533 \text{ m/s}$$

Applying Bernoulli's equation at sections 1 and 2, we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

or $$\frac{50 \times 10^3}{1000 \times 9.81} + \frac{(0.0853)^2}{2 \times 9.81} + 2 = \frac{p_2}{1000 \times 9.81} + \frac{(0.533)^2}{2 \times 9.81} + 0$$

$$5.097 + 3.709 \times 10^{-4} + 2 = \frac{p_2}{9810} + 0.0145$$

$$\therefore \quad p_2 = 69483 \text{ N/m}^2$$

$$= 69.48 \text{ kN/m}^2$$

$$= \mathbf{69.48 \text{ kPa}}$$ **Ans.**

Prob.6. A pipe 300 metres long has a slope of 1 in 100 and tapers from 1 m diameter at the high end to 0.5 m at the low end. Quantity of water flow is 5400 litres per minute. If the pressure at the high end is 70 kPa, find the pressure at the low end. **(R.G.P.V., Dec. 2012)**

Sol. This problem can be solved in a similar way as discussed in Prob.5.

Prob.7. Water is flowing through an inclined conical pipe, 100 m long. It has 600 mm diameter at the upper end and 300 mm at the lower end, the discharge rate is 50 litres/sec. The pipe has a slope 1/2 : 15. Find the pressure at the lower end, if the pressure at the upper end is 2.5 bar. **(R.G.P.V., Dec. 2015)**

Sol. This problem can be solved in a similar way as discussed in Prob.5.

ONLY WORKING PRINCIPLE OF HYDRAULIC MACHINES, PUMPS, TURBINES, RECIPROCATING PUMPS

Q.24. Define hydraulic machines, hydraulic turbines and hydraulic pumps.

Ans. Machines which convert either hydraulic energy into mechanical energy or mechanical energy into hydraulic energy are termed as ***hydraulic machines.***

Hydraulic Turbines – Hydraulic machines which convert hydraulic energy of water into mechanical energy are known as hydraulic turbines. A hydraulic turbine uses the potential and kinetic energy of water and converts it into mechanical energy. The fluid energy is available in the natural or artificial high level water reservoirs which are created by constructing dams at appropriate places in the flow path of rivers. Water falling from a height transfers its energy to the turbine blades. The rotational energy of turbine blades is then utilized to run an electric generator directly coupled to the turbine shaft.

Hydraulic Pumps – The hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps. The hydraulic energy is in the form of pressure energy. Pumps which are designed to raise or transfer the liquids utilize the power. Thus, they are power absorbing machines. The energy absorbed by the pumps makes them enable to overcome the hydraulic resistance and make the liquid rise through a geodetic elevation.

Q.25. Explain with suitable diagram working of a fluid coupling. ***(R.G.P.V., Dec. 2016)***

Or

Describe the working principle of fluid coupling with neat sketch. ***(R.G.P.V., June 2016)***

Or

***Explain construction and working of fluid coupling.* (R.G.P.V., June 2015)**

Or

***What do you understand by fluid coupling ? Explain its working. State its uses.* (R.G.P.V., June 2011)**

Or

***Discuss the working of fluid coupling and state its applications.* (R.G.P.V., Dec. 2010)**

Or

***Explain the working of a fluid coupling.* (R.G.P.V., June 2013)**

Or

***Explain the working principle of a fluid coupling.* (R.G.P.V., June 2008, Dec. 2012)**

Or

***What is fluid coupling ? Explain its working principle.* (R.G.P.V., June 2012)**

Ans. The hydraulic coupling is the device used for transmission of power through a liquid medium. It consists of a pump impeller which is attached to the driving shaft and a turbine runner attached to the driven shaft. These two units are enclosed in a single casing, which contains a liquid, usually oil, due to its lubricating power, availability and stability. No direct contact exists between the driving parts and driven parts. The oil in the casing transmits moment of momentum or torque from pump impeller to the turbine runner shaft.

A typical fluid coupling is shown in fig. 3.7. As the driving shaft is started, the pump impeller causes the fluid to flow from the eye of the pump impeller to the outer periphery of the pump impeller, where it is discharged inwardly through the turbine runner back to the pump. As the speed of the driving shaft is increased, the liquid torque on the turbine runner increases until it overcomes the inertia of the driven unit, and the turbine runner and shaft began to rotate.

The fluid coupling allows a smooth power transmission and eliminates all jerks and roughness. This provide smooth take off and reduces the wear and strain on the drive train. The fluid coupling is very efficient at high engine speeds, but not quite effective at medium speeds.

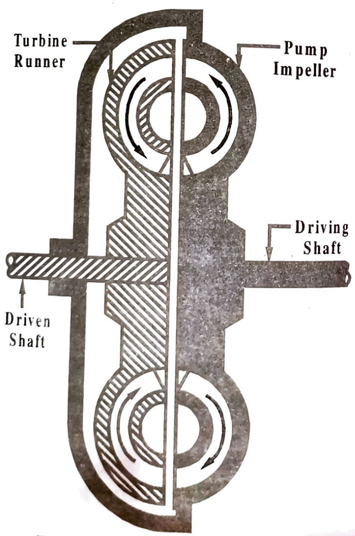


Fig. 3.7 Hydraulic Coupling

Efficiency of Fluid Coupling –

For a fluid coupling,

$$\text{Torque ratio,} \quad \tau_r = \frac{\tau_o}{\tau_i} = 1$$

or

$$\tau_o = \tau_i = \tau \text{ (say)}$$

Thus, the power input to coupling

$$= \tau\omega_i$$

and power output from the coupling

$$= \tau\omega_o$$

where ω_i and ω_o are angular velocities of driving and driven shafts respectively.

The efficiency of fluid coupling,

$$\eta = \frac{\tau\omega_o}{\tau\omega_i} = \frac{\omega_o}{\omega_i} = \frac{N_o}{N_i}$$

Thus, efficiency of a fluid coupling is the ratio of the speed of the driven shaft to that of driving shaft.

Applications – Fluid couplings are widely used with both electrical and internal combustion prime movers (ranging in size from 0.7 kW to 26.5 MW) to transmit torque. The fluid couplings are particularly useful where smooth shock free operations are required and where large initial loads are involved.

Q.26. Define slip of a fluid coupling.

Ans. Slip of a fluid coupling is defined as the ratio of the difference of the speeds of the driving shaft and driven shaft to the speed of the driving shaft. Mathematically it is given as,

$$\text{Slip,} \quad s = \frac{\omega_i - \omega_o}{\omega_i}$$

where, ω_i = Speed of driving shaft

ω_o = Speed of driven shaft.

$$\text{Then,} \quad s = 1 - \frac{\omega_o}{\omega_i} \quad \text{....(i)}$$

$$s = 1 - \eta \quad \left(\because \text{For fluid coupling, } \eta = \frac{\omega_o}{\omega_i}\right)$$

***Q.27. How hydraulic pumps are classified ? Explain.* (R.G.P.V., June 2008, 2013)**

Ans. The pumps can be broadly classified into two categories –

(i) Hydrostatic or positive displacement pumps, e.g. gear pumps and vane pumps.

(ii) Hydrodynamic or non-positive displacement pumps, e.g., centrifugal and axial pumps.

The positive displacement type pumps are known as constant delivery pumps, because they ejects a fixed quantity of pump per revolution of pump shaft. These pumps are fitted with a pressure relief valve to protect them against overpressure, because a positive displacement pump continues to eject fluid even though the outlet valve is fully closed, which can cause an extremely rapid build up in pressure as the fluid is compressed.

Non-positive displacement pumps are known as variable delivery pumps, as the fluid delivered varies with the pressure. These pumps are not self priming. The displacement between inlet and outlet is non-positive type, because there is too much clearance between the rotating and stationary blades to seal against atmospheric pressure. These pumps are used for low pressure high volume flow applications.

The constant delivery or positive displacement pumps may be of following three types –

(i) Gear pumps
  (a) External gear pump (b) Internal gear pumps
  (c) Lobe pumps (d) Screw pumps.
(ii) Vane pumps
(iii) Piston pumps.

Q.28. Define centrifugal pump and its principle.

Ans. The hydraulic machines which convert the mechanical energy into pressure energy by means of centrifugal force acting on the fluid, are called centrifugal pumps. The centrifugal pump acts as a reverse of an inward radial flow reaction turbine. This means that the flow in centrifugal pumps is in the radial outward direction.

The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place. The rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point $\left(\text{i.e., rise in pressure head } = \frac{v^2}{2g} \text{ or } \frac{\omega^2 r^2}{2g}\right)$.

Thus at the outlet of the impeller where radius is more, the rise in pressure head will be more and the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to a high level.

Q.29. Explain working of a centrifugal pump with neat sketch.

Ans. Before starting a pump, priming is done in which suction pipe, casing of pump and a portion of delivery pipe upto delivery valve is completely filled with the liquid which is to be pumped, so that all the air from this portion of pump is expelled out. Then the electric motor is started to rotate the impeller. The rotation of impeller in the casing full of liquid produces a forced vortex which imparts a centrifugal head thus increasing the pressure head of the liquid.

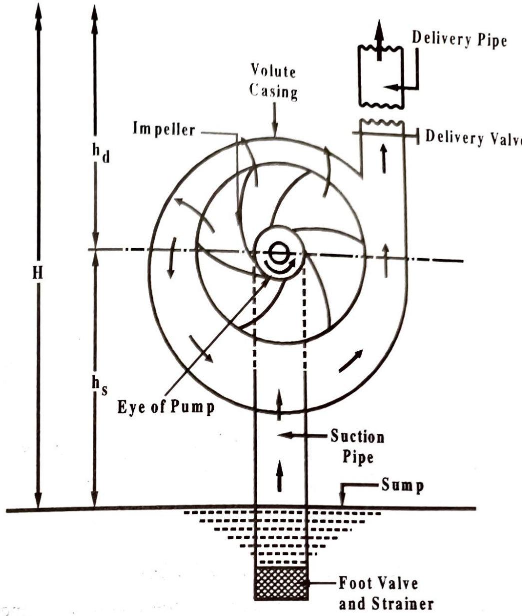


Fig. 3.8 Centrifugal Pump

Thus causing the liquid to be delivered through delivery pipe. Looking at the initial process, the impeller creates a partial vacuum due to centrifugal action at its centre. This partial vacuum helps in the suction of liquid through the suction pipe. The high pressure of the liquid leaving the impeller is utilized in lifting the liquid to required height through delivery pipe.

Q.30. Explain construction of a single stage centrifugal pump with sketches.

Ans. The following are the main parts or components of a centrifugal pump which are shown in fig. 3.9 –

(i) Impeller – It is a device which is coupled to an external source of energy through a shaft. When the external source such as an electric motor imparts the required energy then the impeller rotates on the shaft. It is a wheel which is provided with a series of backward curved blades or vanes.

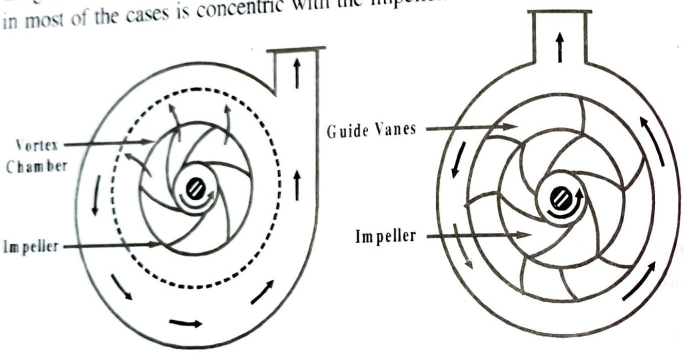
(ii) Casing – It is an air tight passage having gradually varying diameter surrounding the impeller. Due to gradually increasing diameter, it converts kinetic energy into pressure energy before the water leaves the casing and enters the delivery pipe. The following three types of casings are commonly adopted –

(a) Volute Casing – In the volute casing, area of flow increases gradually and casing surrounds the impeller. This increase in area decreases velocity of flow and thus increasing the pressure energy. In case of volute

casing, the efficiency of the pump decreases slightly as a large amount of energy is lost due to the formation of eddies. This type of casing is shown in fig. 3.8.

(b) Vortex Casing – It is shown in fig. 3.9 (a). If a circular chamber called vortex chamber is introduced between the casing and the impeller then the casing is known as vortex casing. By introducing the circular chamber or vortex chamber, formation of eddies can be reduced thus loss of energy can be reduced to a considerable extent. Thus the efficiency of a pump having vortex casing is more than the one having volute casing.

(c) Casing with Guide Blades – This casing is shown in fig. 3.9 (b). In this type, the impeller is surrounded by a series of guide blades mounted on the diffuser. The diffuser or guide vanes are designed in such a way that the water from impeller enters the diffuser without shock. The area between the guide vanes is increasing towards the outside of the diffuser thus helps in decreasing the kinetic energy and increasing the pressure energy at the guide vanes. The water from the impeller passes through the casing which in most of the cases is concentric with the impeller.



(a) Vortex Casing *(b) Casing with Guide Blades*

Fig. 3.9 Different Types of Casing

(iii) Delivery Pipe – A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

(iv) Suction Pipe with a Foot-valve and a Strainer – It is a pipe whose one end is connected to the inlet of the pump and other end immersed in water in a water sump is called suction pipe. A non-return valve known as foot valve is fitted at the lower end of suction pipe which opens only in upward direction. A strainer is also fitted at the lower end of the suction pipe.

Q.31. How can you classify different types of centrifugal pumps ? Briefly describe each of them.

Ans. Centrifugal pumps can be classified in the following manner –

(i) According to the type of casing provided –
(a) Volute pumps (b) Vortex pumps
(c) Diffuser or turbine pumps or casing with guide blades (vanes).

(ii) According to the number of impellers per shaft –
(a) Single stage centrifugal pumps having only one impeller on the shaft.
(b) Multi stage centrifugal pumps having two or more impellers connected in series, mounted on same shaft and are enclosed in the same casing.

(iii) According to the direction of flow of liquid through impeller –
(a) Radial flow pumps are generally provided with radial flow impellers, in which the liquid flows through the impeller in the radial direction only.
(b) Mixed flow pumps are used where large quantity of liquid is being discharged over low heights. In this, the liquid flow through the impeller axially as well as radially.
(c) Axial flow pumps are used to deliver large quantity of liquid at relatively low heads. In this type of pump, the liquid flow through the impeller in axial direction only.

(iv) According to working heads –
(a) Low head pumps can work upto a head of 15 m.
(b) Medium head pumps can work against a head of 15 m to 40 m.
(c) High head pumps can work against a total head above 40 m.

(v) According to the disposition of shafts –
(a) Horizontal disposition of shafts.
(b) Vertical disposition of shafts.

Horizontal disposition of shafts are most common in use. Vertical disposition of shafts pumps are used for deep wells and mines. Vertical disposition of shafts pumps require less space.

(vi) According to the number of entrances to the impeller –
(a) Single suction pumps admits the liquid from one side of the impeller.
(b) Double suction pumps admits the liquid from both sides of the impeller thus axial thrust on the impeller is neutralized and pumps large quantity of liquid.

Q.32. Define the terms – Suction head, delivery head, static head and manometric head.

Ans. **Suction Head –** It is the vertical distance above the water surface in sump to the centre line of the centrifugal pump. This height is also known as suction lift and it is denoted by 'h_s'. This is shown in fig. 3.8.

Delivery Head – It is the vertical distance between the water surface in the tank in which pump delivers water and the centre line of the centrifugal pump. It is denoted by 'h_d' as shown in fig. 3.8.

Static Head – It is the vertical distance between the water level in sump from where water is being sucked and the water level in the tank to which

water is being pumped. Thus this is the sum of static head and the delivery head. It is denoted by H_s.

$$\therefore \quad H_s = h_s + h_d$$

Manometric Head (or Gross Head) – It is the total head against which the centrifugal pump has to work. It is denoted by H_m.

The manometric head is also known as total head or gross head.

Q.33. Differentiate between hydraulic turbines and pumps.

Ans. Differences between hydraulic turbines and hydraulic pumps are given below –

S.No.	*Hydraulic Turbines*	*Hydraulic Pumps*
(i)	Converts hydraulic energy into mechanical energy.	Converts mechanical energy into hydraulic energy.
(ii)	Produces electrical energy.	May utilise electrical energy to produce pressure energy.
(iii)	Very costly and have cumbersome design.	Less costly and easy design considerations.
(iv)	Maintenance cost is high as it has many components.	Less maintenance cost as it has very less components.
(v)	Examples – Pelton turbine, Francis turbine, Kaplan turbine, etc.	Examples – Centrifugal pumps, reciprocating pumps.

***Q.34. Differentiate between turbine and compressor.* (R.G.P.V., June 2012)**

Ans. The differences between turbine and compressor are given below –

S.No.	*Turbine*	*Compressor*
(i)	A turbine converts hydraulic energy into mechanical energy.	A compressor converts mechanical energy into head or pressure energy.
(ii)	A turbine in conjunction with a generator, generates electrical energy.	A compressor is a power consuming device.
(iii)	A turbine is a prime mover.	A compressor has to be driven by a prime mover.

Q.35. Discuss types of water turbines. **(R.G.P.V., June 2016)**

Or

Classify turbines on the basis of type of energy, direction of flow, head and specific speed.

Ans. The classification of hydraulic turbines may be given according to several considerations as indicated below –

(i) According to the Type of Energy at Inlet –

(a) Impulse Turbine – In this turbine, the available energy inside the penstock is converted into kinetic energy or velocity head by passing the water through a nozzle at the end of penstock. The free jet from nozzle impinges on the series of buckets of runner causing it to revolve. A casing is provided at the runner to prevent splashing and to guide the water discharged from buckets to the tail race.

(b) Reaction Turbine – If the water possesses pressure energy as well as kinetic energy at the inlet of the turbine, the turbine is known as reaction turbine. As the water flows through the runner the water is under pressure and pressure energy goes on changing into kinetic energy. The runner is completely enclosed in an air tight casing and casing is completely full of water.

(ii) According to the Direction of Flow Through Runner –

(a) Tangential Flow Turbine – In this type of turbine, water flows along the tangent to the path of rotation of the runner e.g., Pelton wheel.

(b) Radial Flow Turbine – If the water flows in the radial direction through the runner, the turbine is called radial flow turbine.

If water flows from outward to inward radially, the turbine is known as inward radial flow turbine e.g., Francis turbine (old), Thomson turbine, Girard radial flow turbines, etc.

If the water enters at the centre and flows radially outward towards the outer periphery of runner it is called outward radial flow turbine e.g., Fourneyron turbine.

(c) Axial Flow Turbine – When the water enters as well as leaves the runner along the direction parallel to the axis of rotation of the runner, the turbine is called axial flow turbine e.g., Jonval turbine, Girard axial flow turbine, propeller turbine, Kaplan turbine.

(d) Mixed Flow Turbines – Water enters the runner at the outer periphery in the radial direction and leaves the runner in the axial direction or the direction parallel to the axis of rotation of runner, this type of turbine is called mixed flow turbine e.g., Modern Francis turbine is a mixed flow turbine.

(iii) According to Head at the Inlet of the Turbine –

(a) High Head Turbine – These turbines can work under high head ranging from several hundred metres to few thousand metres. These turbines thus require less quantity of water. Generally, the impulse turbines are high head turbines.

(b) Medium Head Turbine – These are capable of working under medium heads ranging from 60 m to 250 m. These type of turbines require large quantity of water e.g., Francis turbine.

(c) Low Head Turbine – These turbines are capable of working under the head less than 60 m. These turbines thus require a large quantity of water. Kaplan turbines and other propeller turbines are low head turbines.

(iv) According to Specific Speed of Turbine –

(a) Low specific speed turbines

(b) Medium specific speed turbines

(c) High specific speed turbines.

Specific speed is the speed of a geometrically similar turbine that would develop one kilowatt power when working under a head of one metre.

The various turbines may be grouped according to the specific speeds are as –

(a) Specific speed varying from 8.5 to 30 – Pelton wheel (for single jet) upto 43 – Pelton wheel (for double jet).

(b) Specific speed varying from 50 to 340 – Francis turbine.

(c) Specific speed varying from 225 to 860 – Kaplan and other propeller turbines.

Q.36. Distinguish between the impulse and reaction turbine.
(R.G.P.V., June 2010)

Ans. Following are the differences between impulse turbine and reaction turbine –

S.No.	Impulse Turbine	Reaction Turbine
(i)	These turbines work on the principle of impulse.	These turbines employ the principle of reaction, i.e. backward force developed opposite to a certain action.
(ii)	Energy available at the turbine inlet is only kinetic energy and the pressure is atmospheric.	Energy available at the turbine inlet is both kinetic energy and pressure energy.
(iii)	In impulse turbine water flows along the tangent of the runner. Thus tangential flow turbine.	In reaction turbine water flows in the radial direction through the runner. Thus radial flow turbine.
(iv)	The turbine is used for high heads ranging from 150 to 2000 m.	The total head of the reaction turbine ranges from about 30 to 500 m.
(v)	It is possible to regulate the flow without loss.	It is not possible to regulate the flow without loss.

Q.37. Distinguish between inward and outward flow reaction turbine.
(R.G.P.V., Dec. 2015)

Ans. The differences between inward and outward flow reaction turbines are given below –

S.No.	Inward Flow Reaction Turbine	Outward Flow Reaction Turbine
(i)	In these turbines, water enters at the outer periphery, flows towards the centre of the turbine and discharges at the inner periphery.	Water enters at the inner periphery, flows outward and discharges at the outer periphery.
(ii)	Here outlet blade velocity is less than the inlet blade velocity, i.e. $u_2 < u_1$. This results in negative centrifugal head imparted on the water, which in turn reduces the relative velocity of water at the outlet.	Here outlet blade velocity is more than the inlet blade velocity, i.e. $u_2 > u_1$. This results in positive centrifugal head imparted on the water, which in turn increases the relative velocity of water at the outlet.
(iii)	The discharge remain constant.	The discharge increases.
(iv)	For any increase in turbine speed, the wheel does not race. The turbine itself adjusts the speed.	With the increase in turbine speed, the wheel tends to race. The turbine cannot adjust the speed by itself.
(v)	Speed control is easy and effective.	Speed control is very difficult.
(vi)	Best suited for large outputs under medium and high heads.	Suitable for low or medium heads.
(vii)	Commonly used for power projects.	Not much in use.

Q.38. Describe the construction and working of Pelton turbine.
(R.G.P.V., Dec. 2010)

Or

Describe the construction and working of any one hydraulic turbine.
(R.G.P.V., June 2011)

Ans. Fig. 3.10 shows the layout of a Pelton turbine in which the water from the reservoir flows through the penstock at the outlet of which a nozzle is fitted. The nozzle increases the kinetic energy of the water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of a jet and strikes the buckets (vanes) of the runner. The jet of water strikes on the buckets with a high velocity and after

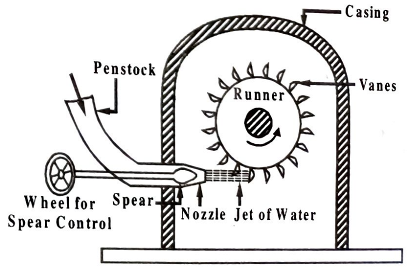


Fig. 3.10 Pelton Turbine

flowing over the vanes, leaving with low velocity, thus imparting energy to the runner.

The main parts of a Pelton turbine are –

(i) Nozzle and Flow Regulating Arrangement – Water striking the buckets (vanes) can be controlled by using a spear in the nozzle. A spear is a conical needle, which is operated either by hand wheel or automatically.

When spear is pushed forward into the nozzle, the amount of water striking the vanes is reduced and if the spear is pushed back, the amount of water striking the runner increases.

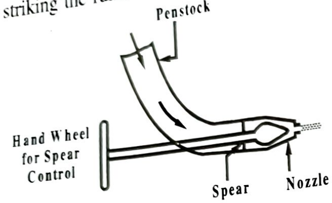


Fig. 3.11 Nozzle with Flow Regulating Arrangement

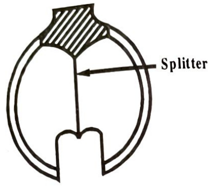


Fig. 3.12 Pelton Wheel Bucket

(ii) Runner with Buckets or Vanes – The runner of a Pelton wheel consists of circular disc on which buckets are evenly spaced and fixed.

The shape of the buckets is of a double hemispherical cup or bowl. Each bucket is divided into two parts by the use of a dividing wall also known as splitter. The buckets are so shaped that the jet of water gets deflected through 160° to 170°.

(iii) Casing – A casing of a Pelton wheel is shown in fig. 3.10. The casing prevents the splashing of water and also directs the used water to the tail race. It is made of cast iron and does not perform any hydraulic function. It also acts as a safeguard against accidents.

(iv) Breaking Jets – When the nozzle is closed, i.e., the supply of hydraulic energy is closed even after that the wheel tends to move due to the inertia and thus wheel tends to revolve for a long time. To stop the runner in a short time, a small nozzle is provided which impinges a jet of water on the back of the vanes. This jet of water is called breaking jet.

Q.39. What is a hydraulic turbine ? Drw a neat sketch of pelton turbine and explain its working. ***(R.G.P.V., Dec. 2014)***

Ans. Refer Q.24 and Q.38.

Q.40. Write a short notes on hydraulic turbine and fluid coupling explaining their working with the help of neat sketches. ***(R.G.P.V., Dec. 2011)***

Ans. **Hydraulic Turbine** – Refer Q.38.

Fluid Coupling – Refer Q.25.

Q.41. Define the terms gross head and net head for a turbine.

Ans. **Gross Head** – Gross head may be defined as the difference between the head race level and tail race level when no water is flowing. Thus, the gross head is often termed as static head or total head. It is denoted by H_g. Mathematically,

$$H_g = \text{Head race level} - \text{Tail race level}$$

Net Head – When water is flowing from the dam to the turbine through the penstock, a loss of head due to friction between water and penstock occurs. There are other losses such as loss due to bend, pipe fittings etc., yet they have very small magnitude as compared to head loss due to friction 'h_f'.

Net head is also called as effective head and is represented by 'H'.

$$\therefore \quad H = H_g - h_f$$

where, H_g = Gross head, and h_f = Head loss due to friction.

According to Darcy-Weisbach formula,

$$h_f = \frac{4.f.L.v^2}{D \times 2g}$$

Q.42. Define various efficiencies related to hydraulic turbines.

Ans. The various efficiencies of a turbine are described as follows –

(i) Hydraulic Efficiency – It is the ratio of power developed at the runner of the turbine to the net power supplied by the water at the entrance of the turbine.

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}} = \frac{R.P.}{W.P.}$$

$$\therefore \quad \eta_h = \frac{R.P.}{W.P.} = \frac{R.P.}{\frac{wQH}{1000}}$$

where, w = Weight density of fluid

Q = Volume of water/sec

H = Net head on turbine.

(ii) Mechanical Efficiency (η_m) – It is the ratio of the power available at the shaft of the turbine known as shaft power (S.P.) or brake power (B.P.) to the power delivered to the runner

$$\eta_m = \frac{\text{Power at the shaft of turbine}}{\text{Power delivered by water to the runner}}$$

$$\therefore \quad \eta_m = \frac{S.P.}{R.P.}$$

(iii) Volumetric Efficiency – It is the ratio of quantity of water actually striking the turbine runner to the quantity of water supplied to the turbine inlet through the nozzle.

Some of the water slips directly to the tail race without striking the runner blades or vanes.

Mathematically, $\eta_v = \dfrac{\text{Volume of water actually striking runner}}{\text{Volume of water supplied to the turbine}}$

(iv) Overall Efficiency – It is the ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine.

Mathematically, $\eta_o = \dfrac{\text{Shaft power}}{\text{Water power}} = \dfrac{S.P.}{W.P.}$

$$= \frac{S.P.}{W.P.} \times \frac{R.P.}{R.P.} = \frac{S.P.}{R.P.} \times \frac{R.P.}{W.P.} = \eta_m \times \eta_h$$

Water power in S.I. $= \dfrac{\rho \times g \times Q \times H}{1000}$ kW

where, $\rho = 1000\ kg/m^3$

$\therefore \quad \eta_o = \dfrac{\text{Shaft power in kW}}{\text{Water power in kW}}$ or $\eta_o = \dfrac{P}{\dfrac{\rho \times g \times Q \times H}{1000}}$

Q.43. Define pump, compressor, turbine, positive displacement machine and pneumatic machine. **(R.G.P.V., Dec. 2013)**

Ans. **Pump** – Refer Q.24.

Compressor – Compressor is a power consuming thermodynamic device which convert mechanical energy into head or pressure energy. Generally compressor is used for supplying high-pressure compressed air, the compressed air is one of the best sources of storing energy. It stores the mechanical energy in the same way as it is stored in a clock-spring when the spring is wound. The mechanical energy if put into air in the form of work in a reversible process, is returnable as work. However, a small amount of this mechanical energy is used up in friction or heat losses. Thus, a machine which receives air from the atmosphere with the aid of some mechanical means and then delivers it to a vessel for storage is known as compressor. Since the process of compressing air requires that work should be done upon it, so a compressor has to be driven by a prime mover.

Turbine – Refer Q.24.

Positive Displacement Machine – A positive displacement machine creates thermodynamic and mechanical action between a near-static fluid and a relatively slow moving surface and involves a volume change or displacement of the fluid.

In a positive displacement machine the fluid expansion or compression occurs without an appreciable displacement of the mass centre of gravity of the contained fluid. The moving surface affects change in fluid volume because of positive containment, i.e. the fluid cannot escape from the boundaries except by leakage. The action is nearly static while the action is dynamic in turbomachines, where energy transfer occurs during fluid flow.

Pneumatic Machine – Machines which are operated by the compressed air are called pneumatic machines. These machines convert compressive energy of air into mechanical work and power. Some commonly used pneumatic machines include pneumatic drill, pneumatic hoists, pneumatic press, pneumatic crane, pneumatic drive, etc.

Q.44. Differentiate compressor with a pump. **(R.G.P.V., Dec. 2016)**

Ans. Refer Q.43 and Q.24.

Q.45. Explain working principle of the positive displacement pumps.

Ans. The positive displacement pumps are those in which the liquid is sucked and then it is actually pushed or displaced due to the thrust exerted on it by a moving member, which results in lifting the liquid to the required height. These pumps usually have one or more chambers which are alternately filled with the liquid to be pumped and then emptied again. The amount of liquid discharged by these pumps almost wholly depends on the speed of the pump. These pumps are generally fitted with a pressure relief valve to protect them against over-pressure, because a positive displacement pump continues to eject liquid even though the outlet valve is fully closed, which can cause an extremely rapid build up in pressure as the fluid is compressed.

Positive displacement pumps can be classified as –

(i) Reciprocating pumps
- (a) Piston plunger pump
- (b) Diaphragm pump.

(ii) Rotary pumps
- (a) Gear pump
- (b) Lobe pump
- (c) Vane pump
- (d) Screw pump
- (e) Rotary plunger pump.

Q.46. What is a reciprocating pump ? Describe the principle and working of a reciprocating pump with neat sketch.

Or

Write short note on – Reciprocating pump. **(R.G.P.V., Dec. 2017)**

Ans. The reciprocating pump is a positive displacement pump which operates on the principle of actual displacement or pushing of liquid by a piston or plunger that reciprocates in a closely fitting cylinder. In reciprocating pumps, when the piston exerts the thrust on the liquid it converts the mechanical energy of driving motor into hydraulic energy (pressure energy).

Fig. 3.13 shows a single acting reciprocating pump. It essentially consists of –

(i) A cylinder in which a piston reciprocates.

(ii) Suction pipe with a non-return suction valve and a delivery pipe with a non-return delivery valve.

(iii) Crank and connecting rod mechanism which may be operated by a steam engine, an I.C. engine or an electric motor.

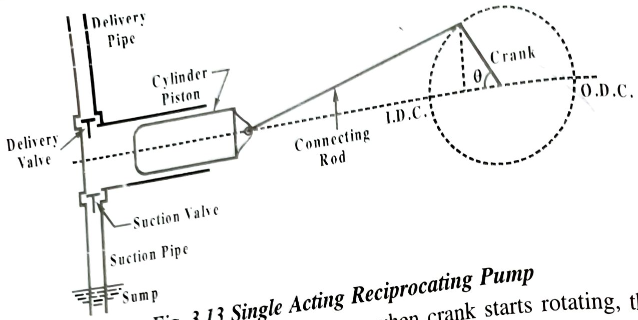


Fig. 3.13 Single Acting Reciprocating Pump

In a single acting reciprocating pump, when crank starts rotating, the piston reciprocates in the cylinder. When crank is at I.D.C., the piston is at the extreme left position in the cylinder. When crank rotates clockwise from I.D.C. to O.D.C., the piston moves towards right and creates a partial vacuum in the cylinder. This vacuum causes suction valve to open and consequently sucks the liquid from sump (which is at atmospheric pressure) into the left side of the cylinder. When the crank reaches at O.D.C., the suction stroke is completed and the left side of cylinder is full of liquid. Now as the crank rotates from O.D.C. to I.D.C., the piston moves towards left and a high pressure is built-up in the cylinder. At this time the suction valve is closed and delivery valve is open. As a result of this the liquid is forced out of the cylinder in the delivery pipe. When the crank reaches at I.D.C., the delivery stroke is completed. The suction and delivery strokes are carried out alternatively and the liquid is pumped from the sump to the delivery pipe.

Q.47. Give a detailed classification of reciprocating pumps.

Ans. The reciprocating pumps may be classified on the basis of –

(i) The water being in contact with one side or both sides of the piston, and

(ii) Number of cylinders.

On the basis of water being in contact with one or both sides of the piston, reciprocating pumps may be classified as

(a) Single acting (b) Double acting.

In a single acting reciprocating pump, the suction and delivery strokes occur alternately, while in a double acting reciprocating pump both strokes occur simultaneously.

On the basis of number of cylinders used in a reciprocating pump, they may be classified as –

(a) Single cylinder pump (b) Double cylinder pump

(c) Triple cylinder pump.

UNIT 4 THERMODYNAMICS AND STEAM ENGINEERING

THERMODYNAMIC SYSTEM, PROPERTIES, STATE, PROCESS

Q.1. Define the term 'thermodynamics'.

Ans. Thermodynamics is the branch of physical sciences. It is a science of energy transfer and the effect of this energy transfer on the properties of substances.

This science is based on the observations of common experiences. These observations are formulated into four basic laws on which this science is developed. They are zeroth law, first law, second law and third law of thermodynamics. These laws govern the principles of energy conversion, especially from heat energy to work energy and vice versa.

Q.2. Define the thermodynamic system. Differentiate between open system, closed system and an isolated system. *(R.G.P.V., Dec. 2017)*

Ans. **Thermodynamic System –** A thermodynamic system can be defined as a definite quantity of matter of fixed mass and identity which is bounded by a closed surface, called boundary. This surface may be real surface, i.e. a vessel containing liquid forms a thermodynamic system with the walls of the vessel forming real boundary surface or, it may be imaginary, i.e. a mass of liquid flowing along a pipe. The boundary surfaces may not be constant in volume and shape. Everything outside the boundary is called surroundings. The thermodynamic system may be broadly defined as a definite area or a space where some thermodynamic process is taking place. It is a region where our attention is focussed for studying a thermodynamic process. System may be as simple as a free body or as complex as a chemical refinery or thermal power plant.

Open System – A system is called an open system or a flow system when energy flow as well as mass flow takes place across the boundary as shown in fig. 4.1.

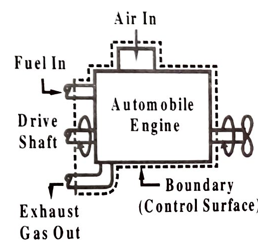


Fig. 4.1 Open System

Examples of open system are –

(i) Diesel or petrol engine in which the fuel-air cross the boundary of the system and work is obtained from the system.

(ii) Air compressor (iii) Gas turbine

(iv) Water pump (v) Condenser, etc.

Closed System – A system is called a closed system or a non-flow system when only energy flow takes place across the boundary but no mass flow takes place. Gas enclosed in a cylinder with a sliding piston is shown in fig. 4.2. is an example of closed system.

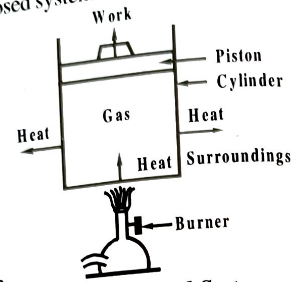


Fig. 4.2 Closed System

Examples of closed system are –

(i) A tank filled with a gas

(ii) A pressure cooker

(iii) A closed refrigerant's circuit in a refrigerator.

Isolated System – A system is called an isolated system when no flow of heat, work and mass takes place across its boundaries. A good example of such type of system is a Thermos Flask, when filled with substance and no mass is taken out of it. Other example is gas enclosed in an insulated box as shown in fig. 4.3.

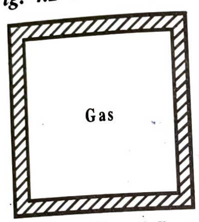


Fig. 4.3 Isolated System

Q.3. Explain an adiabatic system with an example.

Ans. A system is called an adiabatic system when no heat transfer takes place across its boundaries. Mass transfer or work transfer however may take place across the boundary as shown in fig. 4.4. Example of an adiabatic system is –

A gas turbine in which energy is supplied in the form of gas is obtained from work out to rotate the generator. In this system, no heat flow across the boundaries.

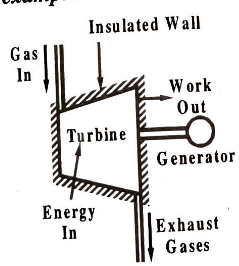


Fig. 4.4 An Adiabatic System

Q.4. Define state of a thermodynamic system.

Ans. The state of a system is its configuration or condition described in sufficient detail so that one state may be distinguished from all other states. The state may be identified by certain macroscopic properties such as temperature, density, pressure, volume, etc.

The state of a system is expressed as a functional relationship between its properties. For example, an equation of state relating three properties of a system such as x, y, z will be

$$f(x, y, z) = 0$$

The number of properties required to define a system depends on the complexity of the system. System which contain more than one component or one phase substance needs more than two independent properties to specify their state.

Q.5. What do you mean by thermodynamic properties ?

Ans. In thermodynamics, a system can be described by certain characteristics. Characteristics, which can be measured, e.g., pressure, temperature, volume, etc. are called properties of the system. Properties at an instant describe the state of the system. When all the properties of a system have definite values, the system is said to exist at a definite state. In thermodynamics the properties like pressure, temperature, volume, density, internal energy, enthalpy, entropy, specific heat, etc. are to be measured oftenly, for the purpose of study. These are known as thermodynamic properties or thermodynamic co-ordinates.

The property depends only on the state of the system and not upon the way on which the state was reached.

If the property is represented by ϕ, then $d\phi$ should be an exact differential.

$$\int_1^2 d\phi = \phi_2 - \phi_1$$

Q.6. Define and discuss the following properties –

(i) Intensive and extensive properties

(ii) Internal and external properties

(iii) Independent and dependent properties.

Ans. (i) Intensive and Extensive Properties –

Intensive Properties –The properties whose values do not depend on mass of the system are known as intensive properties, e.g. pressure, temperature, density, etc.

The properties of unit mass are known as specific properties, e.g. specific volume, specific internal energy, etc. As the specific properties indicate values for unit mass they are independent of total mass. Hence, all specific properties are intensive properties.

Extensive Properties – The values of some of the properties depends upon the mass of the system. They are known as extensive properties, e.g. total volume, weight, surface area, etc.

In order to find whether a given property is intensive or extensive, consider the system uniform throughout and divide it into segments or sub systems by drawing lines across the system in any manner and see whether the property changes or remains constant as one goes from one subsystem to another. If it does not change then it is intensive property otherwise extensive property.

(ii) Internal and External Properties – Internal or thermostatic property is defined as a characteristic of the matter within the equilibrium system. It is measured by an observer at rest relative to the system. Temperature, internal energy, mass, etc. are examples of internal properties.

External or mechanical property is defined as a characteristic of either motion or the position of the system in a gravitational field. It is measured relative to an external datum. Potential energy, kinetic energy, etc. are examples of external or mechanical properties.

(iii) Independent and Dependent Properties – Independent properties are those properties which define the state of the system, while dependent properties are those properties which become fixed when the state of the system is defined by independent properties.

Q.7. Define the term process.

Ans. A change of state occurs when one or more of the properties of a system changes. When a system undergoes changes on its state, it is said to have undergone a process. Process is named according to its specification, i.e. constant volume process, constant pressure process, etc.

Q.8. What is a thermodynamic cycle ?

Ans. When a process or processes are performed on a system in such a way that the final state is identical with the initial state, it is then known as a ***thermodynamic cycle*** or ***cycle*** or ***cyclic process***. In fig. 4.5. A-1-B and A-2-B are processes whereas A-1-B-2-A is a thermodynamic cycle or cyclic process.

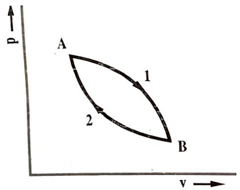


Fig. 4.5 Cyclic Process

ZEROTH, FIRST AND SECOND LAW OF THERMODYNAMICS

Q.9. State and explain Zeroth law of thermodynamics.

Ans. According to Zeroth law of thermodynamics, "when two systems are each in thermal equilibrium with a third system, then the two systems are also in thermal equilibrium with one another".

Zeroth law of thermodynamics gives us the basis for measuring the thermodynamic property called temperature. A reference system known as thermometer is brought in contact separately with two systems, and if the thermometer shows same readings in both the cases, then the two systems are at same temperature.

Explanation – Consider three systems A, B and C as shown in fig. 4.6 perfectly insulated from surrounding and apply the equality of temperature. If the systems A and C are brought into contact, energy in the form of heat will transfer from the body at a higher temperature to the body at a lower temperature. After a certain time they will be in thermal equilibrium. If B and C are brought into contact, after some time, these two will be in thermal equilibrium. Now, if A and B are brought in contact, they will be also in thermal equilibrium. Hence, this suggests that A and B are in thermal equilibrium with each other.

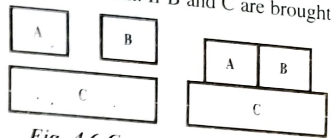


Fig. 4.6 Concept of Zeroth Law

Q.10. State first law of thermodynamics.

Ans. First law of thermodynamics may be stated as,

The energy can neither be created nor destroyed though it can be transformed from one form to another.

According to this law, when a system undergoes a change of state, then both heat transfer and work transfer takes place. The net energy transfer is stored within the system and is known as stored energy or total energy (E) of the system.

First law of thermodynamics may also be stated as,

The heat and mechanical work are mutually convertible.

According to this law, when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer

$$\oint \delta Q = \oint \delta W$$

where symbol $\oint$ stands for cyclic integral, and δQ and δW represent infinitesimal elements of heat and work transfers respectively.

Q.11. State and explain first law of thermodynamics.

(R.G.P.V., Jan./Feb. 2008, Dec. 2008, June 2012)

Ans. For statement of first law of thermodynamics, refer Q.10.

According to the first law of thermodynamics, when a system undergoes a change of state, both heat transfer and work transfer take place. The net energy transfer get stored within the system and known as total energy of the system. Mathematically,

$$\delta Q - \delta W = dE \qquad ...(i)$$

The symbol δ is used for a quantity which is inexact differential and symbol d is used for a quantity which is an exact differential. The quantity E represents total energy of the system at a particular state.

Integrating equation (i) for a change of state from 1 to 2, we have

$$Q_{1\text{-}2} - W_{1\text{-}2} = E_2 - E_1 \qquad ...(ii)$$

For unit mass, equation (ii) becomes

$$q_{1\text{-}2} - w_{1\text{-}2} = e_2 - e_1$$

where, E_1, E_2 = Total energy of the system at states 1 and 2 respectively.

$Q_{1\text{-}2}$ = Heat transferred to the system during the process from state 1 to state 2.

$W_{1\text{-}2}$ = Work done by the system on the surroundings during the process.

Total energy of the system at state 1,

$$E_1 = P.E._1 + K.E._1 + U_1 = mgz_1 + \frac{mV_1^2}{2} + U_1$$

where, $P.E._1$ = Potential energy at state 1
$K.E._1$ = Kinetic energy at state 1
U_1 = Internal energy at state 1
m = Mass of the body
g = Acceleration due to gravity
z_1 = Distance through which the body falls
V_1 = Velocity of the body.

Total energy of the system at state 2,

$$E_2 = P.E._2 + K.E._2 + U_2 = mgz_2 + \frac{mV_2^2}{2} + U_2$$

Substituting values in equation (ii), we get

$$Q_{1\text{-}2} - W_{1\text{-}2} = P.E._2 + K.E._2 + U_2 - (P.E._1 + K.E._1 + U_1)$$
$$= (P.E._2 - P.E._1) + (K.E._2 - K.E._1) + (U_2 - U_1)$$
$$= m(gz_2 - gz_1) + m\left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + (U_2 - U_1)$$

For unit mass

$$q_{1\text{-}2} - w_{1\text{-}2} = (gz_2 - gz_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + (u_2 - u_1) \quad ...(iii)$$

The equation (iii) is known as ***steady flow energy equation.***

When $P.E._1 = P.E._2$, then

$$Q_{1\text{-}2} - W_{1\text{-}2} = (K.E._2 - K.E._1) + (U_2 - U_1)$$

When $P.E._1 = P.E._2$ and $K.E._1 = K.E._2$, then

$$Q_{1\text{-}2} - W_{1\text{-}2} = (U_2 - U_1) = dU$$

For an isolated system for which $Q_{1\text{-}2} - W_{1\text{-}2} = 0$

$$E_2 = E_1$$

This shows that the first law of thermodynamics is the law of conservation of energy.

Q.12. Enlist shortcomings of first law of thermodynamics.

Ans. Limitations of the first law of thermodynamics are as follows –

(i) According to the first law of thermodynamics "when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer".

This statement does not specify the direction of flow of heat and work, i.e., whether the heat flows from a hot body to a cold body or from a cold body to a hot body. It also does not give any condition in which these transfers take place.

(ii) The heat energy and mechanical work are mutually convertible. Though the mechanical work can be fully converted into heat energy, but only a part of heat energy can be converted into mechanical work. This means that the heat energy and mechanical work are not fully mutually convertible. In other words, there is a limitation on the conversion of one form of energy into another form.

(iii) Energy can neither be created nor destroyed, but can be transformed from one form to another.

A machine which violates the above statement is known as perpetual motion machine of the first kind. Such a machine is impossible to obtain in actual practice.

Q.13. State and explain second law of thermodynamics.
(R.G.P.V., June 2008, 2013, 2014)

Or

What is second law of thermodynamics ? Explain the two statements of this law.
(R.G.P.V., Dec. 2011)

Or

Write down Kelvin-Planck and Clausius equation of second law of thermodynamics.
(R.G.P.V., Sept. 2009)

Or

Write and discuss the Kelvin-Planck and Clausius statements of the second law of thermodynamics.
(R.G.P.V., Dec. 2017)

Ans. The second law states that heat will not pass automatically from a colder body to a hotter body. Heat can be forced to pass to a higher temperature, as in the action of a refrigerating machine, but only by applying an "external agency" to drive the machine, i.e. by doing work on the system.

The two statements of second law of thermodynamics are as follows –

(i) ***Kelvin-Planck Statement*** – It is impossible to construct a heat engine which, while operating in a thermodynamic cycle, produces no other effect except to extract heat from a single reservoir and do equivalent amount of work.

Explanation – Consider an engine which receives heat Q_1 from reservoir and rejects heat Q_2 to the sink and produces work W_E as shown in fig. 4.7. The efficiency of the engine,

$$\eta = \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} \quad \text{or} \quad \eta = \frac{W_E}{Q_1}$$

However experience shows that Q_1 is always greater than W_E or in other words some heat has to be rejected to the sink to produce work W_E. This means that efficiency of the engine can never be 100%.

If we consider an engine violating second law of thermodynamics (Kelvin-Planck statement) in that case $Q_2 = 0$ and efficiency of the engine will be 100%, i.e. all heat supplied will be converted into work. Such an engine will produce work in a complete cycle by exchanging heat with only one reservoir.

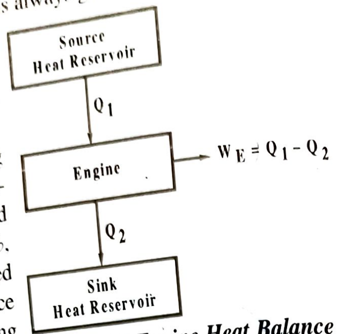


Fig. 4.7 Engine Heat Balance

This type of engine is called perpetual motion machine of second kind **(PMM2)**. PMM2 engine does not violate first law of thermodynamics but it does violate second law of thermodynamics.

(ii) ***Clausius Statement*** – It is impossible to construct a heat pump which operating in a cycle will remove heat continuously from a lower temperature reservoir and transfer to a higher temperature reservoir without any amount of external work being done on it.

Explanation – The Clausius statement of the second law of thermodynamics can be explained with the help of refrigeration cycle as shown in fig. 4.8.

The function of the domestic refrigerator is to take out heat from a body at low temperature and deliver it to a body at high temperature, in a cyclic process.

The transfer of heat from a body at low temperature to a body at high temperature is possible with the help of external aid, i.e. when work is done on the system. The heat balance is then,

$$Q_1 + W_R = Q_2$$

The evaporator coil is placed in the area (cold reservoir) from where heat (Q_2) is to be extracted and condenser coil rejects heat (Q_1) to the atmosphere. A vapour compressor supplies work W_R makes removal of heat from cold body and its rejection to hot body possible.

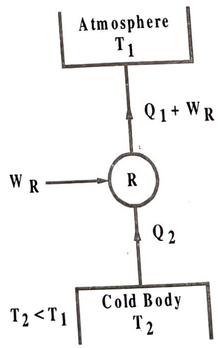


Fig. 4.8 Refrigeration Cycle

The equivalence of Clausius and Kelvin-Planck statements can be illustrated by proving that violation of each statement leads to violation of the other.

Fig. 4.9 shows a cyclic heat engine that is supposed to violate the Kelvin-Planck statement. It removes heat (Q_1) from a high temperature reservoir and converts it completely to work (W_E). Thus the work of the engine is,

$$W_E = Q_1$$

The work output W_E of engine is used to operate the refrigerator which takes in heat Q_2 from the low temperature reservoir.

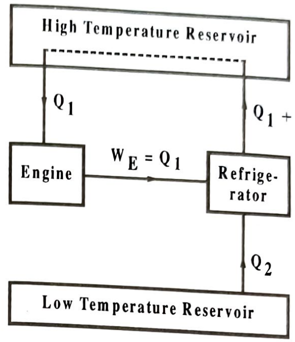


Fig. 4.9

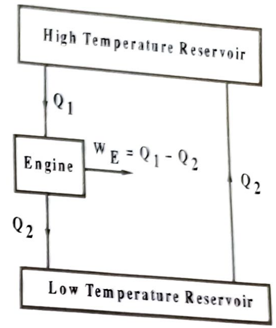


Fig. 4.10

By the first law of thermodynamics, the magnitude of heat rejected by refrigerator to the high temperature reservoir is,

$$Q_2 + W_E = Q_2 + Q_1$$

Out of the heat ($Q_2 + Q_1$) rejected to the high temperature reservoir, a part Q_1 can be diverted to furnish the heat input to the engine. Thus there would remain a net flow of heat of magnitude Q_2 from a low temperature reservoir to a high temperature reservoir. The engine and refrigerator combined would thus operate continuously, the engine providing just sufficient work to drive the refrigerator. This device would therefore violate the Clausius statement also.

A device that violates the Clausius statement is shown in fig. 4.10.

Heat flows continuously from the low temperature reservoir to the high temperature reservoir at the rate Q_2. Now, we operate an engine between the two reservoirs. Engine takes in heat at the rate Q_1 from the high temperature reservoir, does work W_E and rejects heat of magnitude ($Q_1 - W_E$) to the low temperature reservoir. It ensures that the heat rejected by the engine at the same rate Q_2 at which it flows from the low temperature reservoir to the high temperature reservoir.

Thus, $$Q_1 - W_E = Q_2$$

or $$Q_1 = Q_2 + W_E$$

This device will also operate continuously and its sole effect is to remove heat at the rate $(Q_1 - Q_2)$ from a single reservoir and convert it completely into work. This device would therefore violate the Kelvin-Planck statement also.

Since a violation of Kelvin-Planck statement constitutes also a violation of Clausius statement and vice versa, we conclude that the two statements are equivalent.

Q.14. Write down two statements of second law of thermodynamics. ***(R.G.P.V., June 2015)***

Ans. Refer Q.13.

NUMERICAL PROBLEMS

Prob.1. A cylinder with air comprises the system. The cycle is completed as follows –

(i) 82000 N-m work is done by the piston on the air during compression and 45 kJ of heat is rejected to the surroundings.

(ii) During expansion, 100000 N-m of work is done by the air on the piston. Determine the quantity of heat added to the system.

Sol. Let processes 1-2 and 2-1 be the compression and expansion processes respectively and thus the cycle is complete. During compression process 1-2, we have from first law of thermodynamics,

$$Q_{1-2} - W_{1-2} = dU = U_2 - U_1$$

or

$$-45 - \frac{(-82000)}{1000} = U_2 - U_1 \qquad (\because 1 \text{ N-m} = 1 \text{ J})$$

$$U_2 - U_1 = 37 \text{ kJ}$$

It is to be noted that Q is positive when heat is taken from surroundings to system and W is positive when the work is delivered from system to surroundings. Hence for process 1-2, Q and W are negative.

Again for expansion process 2-1, we have

$$Q_{2-1} - W_{2-1} = U_1 - U_2$$

or

$$Q_{2-1} = \frac{100000}{1000} - 37 = \mathbf{63\ kJ} \qquad \text{Ans.}$$

THERMODYNAMIC PROCESSES AT CONSTANT PRESSURE, VOLUME, ENTHALPY & ENTROPY

Q.15. What is meant by thermodynamic work ?

Ans. Work is said to be done by a system if the sole effect external to the system can be reduced to the raising of a weight.

Thus, in thermodynamics –

(i) Work is either done on a system or it is done by the system.

(ii) The effect of work can be converted to the raising of weight although in its original form it may not appear to raise the weight.

(iii) The energy which can raise a weight can also turn a shaft against the resistance. Hence this kind of work is also known as shaft work.

(iv) Work is a form of energy which crosses the boundary. It is exclusive in nature and is different from any other energy carried away by the mass across the boundary of the system.

Q.16. Define the terms flow work and non-flow work.

Ans. **Flow Work –** The flow work is the work required to cause the flow of fluid across the control volume. The flow work is significant only in a flow process or an open system, because in a closed system, there is no flow of fluid across the system. The magnitude of the flow work per unit mass of fluid is uniquely expressible by the simple product of the two properties of the fluid, pressure and specific volume.

Non-flow Work – Non-flow work is defined as the energy transferred, without transfer of mass across the boundary of a system because of an intensive property difference other than temperature that exists between system and surroundings.

Q.17. Define non-flow process. Name some non-flow processes.

Ans. The processes occurring in closed system in which there is no transfer of mass are termed as non-flow processes. For a non-flow process flow work is zero. Some common non-flow or closed system processes are –

(i) Constant volume process

(ii) Constant pressure or isobaric process

(iii) Constant temperature or isothermal process

(iv) Adiabatic or isentropic process

(v) Polytropic process.

Q.18. What is the significance of the term $\int pdv$ in a non-flow process.

Or

Prove that work done for a non-flow process, $W = \int_1^2 pdv$.

Ans. Consider a closed system as shown in fig. 4.11, undergoing a non-flow process.

The net pressure of the fluid in the system acts on the piston and causes movement of the piston.

The force on the piston is given by,

$$F = p.A$$

where p = Net pressure on fluid

A = Area of cross-section of piston.

Let the piston moves through a small distance 'dx' then work done on the piston is

$$dW = p.A\,dx$$

But, A.dx is change in volume. Thus, work done for a small movement of piston will be.

$$dW = p\,dv$$

If fluid expands from state 1 to state 2, then work done will be given by,

$$W = \int_1^2 p\,dv$$

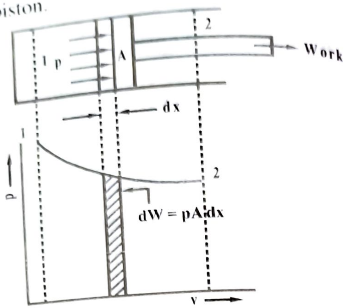
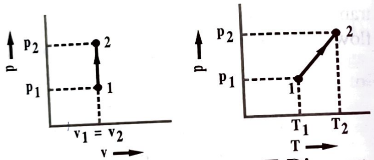


Fig. 4.11 Closed System

Thus, the term $\int pdv$ represents the work done during a non-flow process. The work done in above expression represents area below the curve 1-2. To determine the magnitude of work done, path followed is need to be specified and for determining path, process should be in equilibrium at every point of the path.

Q.19. What is constant volume process ? Derive expressions for the work done, change in internal energy, heat transfer and change in enthalpy.

Ans. Constant volume process is shown on the p-v and p-T diagrams in fig. 4.12 (a) and (b) respectively.



(a) p-v Diagram ***(b) p-T Diagram***

Fig. 4.12 Constant Volume Process

When a gas is heated at a constant volume, its temperature and pressure will increase. Since there is no change in its volume, therefore no work is done by the gas. All the heat supplied to the gas is stored within the gas in the form of internal energy. Now consider **m kg** of a certain gas being heated at constant volume from state 1 to state 2.

Let, p_1, v_1, T_1 = Pressure, volume and temperature at state 1

p_2, v_2, T_2 = Pressure, volume and temperature at state 2.

The general gas equation is

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

Since $v_1 = v_2$, therefore

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \text{ or } \frac{p}{T} = \text{Constant}$$

(i) Work done by the gas

We know that

$$\delta W = p\,dv \qquad ...(i)$$

On integrating equation (i) from state 1 to state 2.

$$\int_1^2 \delta W = \int_1^2 p\,dv = p\int_1^2 dv$$

or $$W_{1-2} = p\,(v_2 - v_1) = 0 \qquad (\because v_1 = v_2)$$

Work done in constant volume process is zero.

(ii) Change in internal energy

$$dU = mc_v\,dT$$

where, c_v = Specific heat of gas at constant volume.

Integrating from state 1 to state 2, we get

$$\int_1^2 dU = mc_v \int_1^2 dT$$

or $$U_2 - U_1 = mc_v\,(T_2 - T_1)$$

(iii) Heat transfer

We know that $\delta Q = dU + \delta W$

Integrating from state 1 to state 2, we get

$$\int_1^2 \delta Q = \int_1^2 dU + \int_1^2 \delta W$$

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$

$$Q_{1-2} = U_2 - U_1 = mc_v\,(T_2 - T_1) \qquad (\because W_{1-2} = 0)$$

(iv) Change in enthalpy

$$dH = dU + d(pv)$$

Integrating from state 1 to state 2, we get

$$\int_1^2 dH = \int_1^2 dU + \int_1^2 d(pv)$$

or $$H_2 - H_1 = (U_2 - U_1) + (p_2 v_2 - p_1 v_1)$$

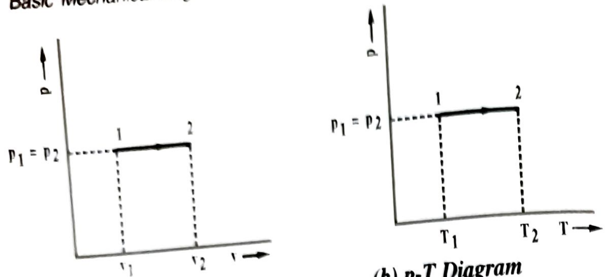
$$= mc_v\,(T_2 - T_1) + mR\,(T_2 - T_1)$$

$$(\because p_1 v_1 = mRT_1 \text{ and } p_2 v_2 = mRT_2)$$

$$= m\,(T_2 - T_1)\,(c_v + R) = mc_p\,(T_2 - T_1) \qquad (\because c_p - c_v = R)$$

Q.20. Explain constant pressure process or isobaric process.

Ans. The constant pressure process is shown on p-v and p-T diagrams in fig. 4.13 (a) and (b) respectively.



(a) p-v Diagram (b) p-T Diagram

Fig. 4.13 Constant Pressure Process

When a gas is heated at a constant pressure its temperature and volume will increase. Since there is a change in its volume, therefore the heat supplied to the gas is utilized to increase the internal energy of the gas and for doing some external work.

Consider m kg of gas being heated at constant pressure from state 1 to state 2.

Let, p_1, v_1, T_1 = Pressure, volume and temperature at state 1

p_2, v_2, T_2 = Pressure, volume and temperature at state 2.

The general gas equation is

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

Since, the gas is heated at constant pressure, therefore $p_1 = p_2$.

$$\frac{v_1}{T_1} = \frac{v_2}{T_2} \text{ or } \frac{v}{T} = \text{Constant}$$

(i) Work done by the gas

$$\delta W = p\,dv$$

Integrating from state 1 to state 2, we get

$$\int_1^2 \delta W = \int_1^2 p\,dv = p\int_1^2 dv$$

$$W_{1-2} = p\,(v_2 - v_1) = mR\,(T_2 - T_1)$$

$$(\because pv_1 = mRT_1 \text{ and } pv_2 = mRT_2)$$

(ii) Change in internal energy

$$dU = U_2 - U_1 = mc_v\,(T_2 - T_1)$$

(iii) Heat supplied or heat transferred

$$\delta Q = \delta U + \delta W$$

Integrating from state 1 to state 2, we get

$$\int_1^2 \delta Q = \int_1^2 \delta U + \int_1^2 \delta W$$

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$
$$= mc_v\,(T_2 - T_1) + mR\,(T_2 - T_1)$$
$$= m\,(T_2 - T_1)\,(c_v + R)$$
$$= m\,c_p\,(T_2 - T_1) \qquad (\because c_p - c_v = R)$$

(iv) Change in enthalpy

$$dH = H_2 - H_1 = m\,c_p\,(T_2 - T_1)$$

If the gas is cooled at a constant pressure, then there will be a compression. During cooling, the temperature and volume will decrease and work is said to be done on the gas. In this case,

Work done $\quad W_{1-2} = p\,(v_1 - v_2) = mR\,(T_1 - T_2)$

Change in internal energy,

$$dU = U_1 - U_2 = mc_v\,(T_1 - T_2)$$

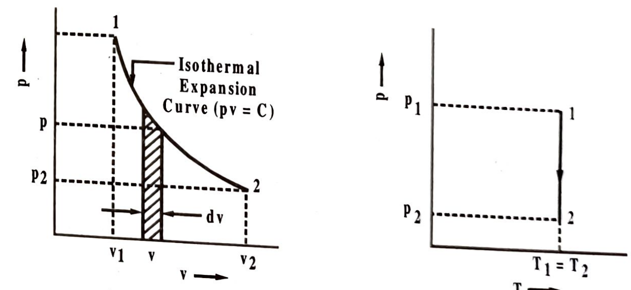
Heat rejected $\quad Q_{1-2} = mc_p\,(T_1 - T_2)$

During expansion or heating process, work is done by the gas (i.e., W_{1-2} is positive); internal energy of the gas increases (i.e., dU is positive) and heat is supplied to the gas (i.e., Q_{1-2} is positive).

During compression or cooling process, work is done on the gas (i.e., W_{1-2} is negative); internal energy of the gas decreases (i.e., dU is negative) and heat is rejected by the gas (i.e., Q_{1-2} is negative).

Q.21. Explain constant temperature or isothermal process.

Ans. The isothermal process is shown on p-v and p-T diagrams in fig. 4.14 (a) and (b) respectively.



(a) p-v Diagram **(b) p-T Diagram**

Fig. 4.14 Isothermal Process

A constant temperature or isothermal process is one in which the temperature of the working substance remains constant during its expansion or compression.

In an isothermal process, there is no change in temperature, internal energy and enthalpy.

Consider m kg of gas being heated at constant temperature from state 1 to state 2.

Let, p_1, v_1, T_1 = Pressure, volume and temperature at state 1

p_2, v_2, T_2 = Pressure, volume and temperature at state 2.

The general gas equation is

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

$\because$ The gas is heated at constant temperature, therefore

$$T_1 = T_2$$

$\therefore$ $$p_1 v_1 = p_2 v_2 \text{ or } pv = \text{Constant}$$

(i) Work done by the gas

$$\delta W = p\, dv$$

Integrating from state 1 to state 2, we get

$$\int_1^2 \delta W = \int_1^2 p\, dv$$

or $$W_{1\text{-}2} = \int_1^2 p\, dv \qquad \text{...(i)}$$

$\because$ The expansion of the gas is isothermal, i.e. pv = C,

$\therefore$ $$pv = p_1 v_1 \text{ or } p = \frac{p_1 v_1}{v}$$

Substituting this value of p in equation (i), we get

$$W_{1\text{-}2} = \int_{v_1}^{v_2} \frac{p_1 v_1}{v} dv = p_1 v_1 \int_{v_1}^{v_2} \frac{dv}{v}$$

$$= p_1 v_1 \left[\log_e v\right]_{v_1}^{v_2} = p_1 v_1 \log_e \left(\frac{v_2}{v_1}\right) \qquad \text{...(ii)}$$

The equation (ii) may be expressed in terms of corresponding logarithm to the base 10, i.e.

$$W_{1\text{-}2} = 2.3\, p_1 v_1 \log \left(\frac{v_2}{v_1}\right) = 2.3\, p_1 v_1 \log r \qquad \text{...(iii)}$$

where, $r = \frac{v_2}{v_1}$, and is known as expansion ratio.

The equation (iii) may also be written as

$$W_{1\text{-}2} = 2.3 \text{ mRT} \log \left(\frac{v_2}{v_1}\right) = 2.3 \text{ mRT} \log r$$

$$(\because p_1 v_1 = p_2 v_2 = \text{mRT})$$

Since $p_1 v_1 = p_2 v_2$, therefore $\frac{v_2}{v_1} = \frac{p_1}{p_2}$

$\therefore$ Work done, $$W_{1\text{-}2} = 2.3\, p_1 v_1 \log \left(\frac{p_1}{p_2}\right)$$

Expansion ratio, $$r = \frac{\text{Volume at the end of expansion}}{\text{Volume at the beginning of expansion}}$$

Compression ratio, $$r = \frac{\text{Volume at the beginning of compression}}{\text{Volume at the end of compression}}$$

(ii) Change in internal energy,

$$dU = U_2 - U_1 = mc_v (T_2 - T_1)$$

or $$dU = U_2 - U_1 = 0 \text{ or } U_1 = U_2 \qquad (\because T_1 = T_2)$$

(iii) Heat supplied or heat transferred

$$Q_{1\text{-}2} = dU + W_{1\text{-}2} = W_{1\text{-}2} \qquad (\because dU = 0)$$

In this process, all the heat supplied to the gas is equal to the work done by the gas.

(iv) Change in enthalpy

$$dH = H_2 - H_1 = mc_p (T_2 - T_1) \qquad (\because T_1 = T_2)$$

or $$dH = H_2 - H_1 = 0 \text{ or } H_1 = H_2$$

Q.22. Explain with neat sketch an adiabatic process or isentropic process.

Ans. Adiabatic process is shown on the p-v diagram in fig. 4.15.

In adiabatic process, the working substance neither receives nor gives out heat to its surroundings, during its expansion or compression. In an adiabatic process no heat leaves or enters the gas, the temperature of the gas changes and the change in internal energy is equal to the work done.

Consider m kg of gas being heated adiabatically from state 1 to state 2.

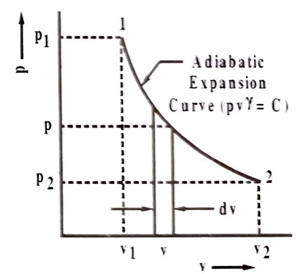


Fig. 4.15 Adiabatic Process

Let, p_1, v_1, T_1 = Pressure, volume and temperature at state 1

p_2, v_2, T_2 = Pressure, volume and temperature at state 2.

From first law of thermodynamics,

$$\delta Q = \delta W + \delta U \qquad \text{...(i)}$$

$\because$ No heat transfer takes place, therefore

$$\delta Q = 0$$

$\therefore$ $$\delta W + \delta U = 0$$

or $$p\,dv + mc_v\,dT = 0 \qquad \text{...(ii)}$$

$\therefore$ $$dT = \frac{-p\,dv}{mc_v} \qquad \text{...(iii)}$$

We know that $pv = mRT$

Differentiating equation (iii), we get

$$p\,dv + v\,dp = mRdT$$

$\therefore$ $$dT = \frac{p\,dv + v\,dp}{mR} = \frac{p\,dv + v\,dp}{m(c_p - c_v)} \qquad \text{...(iv)}$$

Equating equations (ii) and (iv), we get

$$\frac{-p\,dv}{mc_v} = \frac{p\,dv + v\,dp}{m(c_p - c_v)}$$

$$\frac{c_p - c_v}{c_v} = \frac{p\,dv + v\,dp}{-p\,dv} = -1 - \frac{v\,dp}{p\,dv}$$

$$\frac{c_p}{c_v} - 1 = -1 - \left(\frac{v}{dv} \times \frac{dp}{p}\right)$$

$$\gamma = -\left(\frac{v}{dv} \times \frac{dp}{p}\right) \qquad \left(\because \frac{c_p}{c_v} = \gamma\right)$$

$\therefore$ $$\gamma \times \frac{dv}{v} = -\frac{dp}{p} \text{ or } \gamma \times \frac{dv}{v} + \frac{dp}{p} = 0$$

Integrating both sides,

$$\gamma \log_e v + \log_e p = \text{Constant}$$

or $$\log_e pv^\gamma = \log_e C$$

$\therefore$ $$pv^\gamma = C \text{ or } p_1 v_1^\gamma = p_2 v_2^\gamma = \ldots\ldots = C \qquad \text{...(v)}$$

The equation (v) may also be expressed as

$$\frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^\gamma \qquad \text{...(vi)}$$

From general gas equation,

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2} \text{ or } \frac{p_1}{p_2} = \frac{T_1}{T_2} \times \frac{v_2}{v_1} \qquad \text{...(vii)}$$

Equating equations (vi) and (vii), we get

$$\left(\frac{v_2}{v_1}\right)^\gamma = \frac{T_1}{T_2} \times \frac{v_2}{v_1}$$

or $$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^\gamma \times \frac{v_1}{v_2} = \left(\frac{v_2}{v_1}\right)^\gamma \left(\frac{v_2}{v_1}\right)^{-1}$$

$\therefore$ $$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma - 1} \qquad \text{...(viii)}$$

From equation (vi), we also know that

$\therefore$ $$\frac{v_1}{v_2} = \left(\frac{p_1}{p_2}\right)^{-\frac{1}{\gamma}} \qquad \text{...(ix)}$$

From the general gas equation

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2} \text{ or } \frac{v_1}{v_2} = \frac{T_1}{T_2} \times \frac{p_2}{p_1} \qquad \text{...(x)}$$

Equating equations (ix) and (x), we get

$$\left(\frac{p_1}{p_2}\right)^{-1/\gamma} = \frac{T_1}{T_2} \times \frac{p_2}{p_1}$$

or $$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{-\frac{1}{\gamma}} \times \left(\frac{p_1}{p_2}\right) = \left(\frac{p_1}{p_2}\right)^{-\frac{1}{\gamma} + 1}$$

$\therefore$ $$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma - 1}{\gamma}} \qquad \text{...(xi)}$$

(i) Work done

$$\delta W = p\,dv$$

Integrating from state 1 to state 2,

$$\int_1^2 \delta W = \int_1^2 p\,dv \text{ or } W_{1\text{-}2} = \int_{v_1}^{v_2} p\,dv \qquad \text{...(xii)}$$

Expansion follows the law

$$pv^\gamma = p_1 v_1^\gamma \text{ or } p = \frac{p_1 v_1^\gamma}{v^\gamma}$$

Substituting value of p in equation (xii), we get

$$W_{1\text{-}2} = \int_{v_1}^{v_2} \frac{p_1 v_1^\gamma}{v^\gamma} dv = p_1 v_1^\gamma \int_{v_1}^{v_2} v^{-\gamma} dv = p_1 v_1^\gamma \left[\frac{v^{-\gamma+1}}{-\gamma+1}\right]_{v_1}^{v_2}$$

$$= \frac{p_1 v_1^\gamma}{1-\gamma}\left[v_2^{1-\gamma} - v_1^{1-\gamma}\right] = \frac{p_1 v_1^\gamma v_2^{1-\gamma} - p_1 v_1^\gamma v_1^{1-\gamma}}{1-\gamma}$$

$$= \frac{p_2 (v_2^\gamma v_2^{1-\gamma}) - p_1 (v_1^\gamma v_1^{1-\gamma})}{1-\gamma} \qquad (\because p_1 v_1^\gamma = p_2 v_2^\gamma)$$

$$= \frac{p_2 v_2 - p_1 v_1}{1-\gamma} = \frac{p_1 v_1 - p_2 v_2}{\gamma - 1} \qquad \text{(For expansion)}$$

$$= \frac{p_2V_2 - p_1V_1}{\gamma - 1} \quad \text{(For compression)}$$

or
$$W_{1-2} = \frac{mR(T_1 - T_2)}{\gamma - 1} \quad \text{(For expansion)}$$

$$= \frac{mR(T_2 - T_1)}{\gamma - 1} \quad \text{(For compression)}$$

(ii) Change in internal energy

$$dU = U_2 - U_1 = mc_v(T_2 - T_1)$$

(iii) Heat supplied or heat transferred

$$Q_{1-2} = 0$$

(iv) Change in enthalpy

$$dH = H_2 - H_1 = mc_p(T_2 - T_1)$$

NUMERICAL PROBLEMS

Prob.2. The pressure-volume correlation for a non-flow reversible (quasi-static) process is given by p = (8 – 4V) bar, where V is in m³. If 150 kJ of work is supplied to the system, determine the final pressure and volume of the system. Take initial volume 0.6 m³. ***(R.G.P.V., Dec. 2015)***

Sol. Given, $p = (8 - 4V)$ bar $= (8 - 4V) \times 10^5$ N/m², $W_{1-2} = -150$ kJ $= -150 \times 10^3$ J, $V_1 = 0.6$ m³.

Work done for a non-flow quasi-static process is given by

$$W_{1-2} = \int_{V_1}^{V_2} p\, dV$$

$$-150 \times 10^3 = \int_{0.6}^{V_2} (8 - 4V) \times 10^5 dV$$

$$-150 \times 10^3 = \left[(8V - 2V^2) \times 10^5\right]_{0.6}^{V_2}$$

or
$$-1.5 = [(8V_2 - 2(V_2)^2) - (8 \times 0.6 - 2 \times (0.6)^2)]$$

$$-1.5 = 8V_2 - 2(V_2)^2 - 4.8 + 0.72$$

or
$$2(V_2)^2 - 8V_2 + 2.58 = 0$$

On solving above equation, we get

$$V_2 = 3.65 \text{ m}^3 \text{ or } 0.35 \text{ m}^3$$

Using $V_2 = 3.65$ m³ will give the –Ve final pressure which is not possible, thus final volume of the system will be

$$V_2 = \mathbf{0.35\ m^3} \quad \textbf{Ans.}$$

and final pressure will be

$$p_2 = (8 - 4V_2)\text{bar}$$
$$= 8 - 4 \times 0.35 = \mathbf{6.6\ bar} \quad \textbf{Ans.}$$

Prob.3. A perfect gas expands such that its pressure varies in a linear relationship with volume –

$$p = av + b$$

where a and b are constants.

If the initial and final states of the gas are 4 bar, 0.1 m³ and 2 bar, 0.2 m³, determine work interaction.

Sol. Given, $p_1 = 4$ bar $= 400$ kPa, $v_1 = 0.1$ m³, $p_2 = 2$ bar $= 200$ kPa, $v_2 = 0.2$ m³.

At initial state,
$$p_1 = av_1 + b$$
$$400 = 0.1a + b \quad \text{....(i)}$$

and at final state,
$$p_2 = av_2 + b$$
$$200 = 0.2a + b \quad \text{....(ii)}$$

Solving equations (i) and (ii), we get

$$a = -2000 \text{ kPa/m}^3 \text{ and } b = 600 \text{ kPa}$$

Now net work interaction,

$$W_{1-2} = \int_{v_1}^{v_2} p\, dv = \int_{v_1}^{v_2} (av + b)\, dv$$

$$= \left[\frac{av^2}{2} + bv\right]_{v_1}^{v_2} = \left[\frac{-2000v^2}{2} + 600v\right]_{0.1}^{0.2}$$

$$= \left[-1000v^2 + 600v\right]_{0.1}^{0.2}$$

$$= [\{-1000(0.2)^2 + 600 \times 0.2\} - \{-1000 \times (0.1)^2 + 600 \times 0.1\}]$$

$$= [-40 + 120 + 10 - 60] = \mathbf{30\ kJ} \quad \textbf{Ans.}$$

Prob.4. A gas of mass 1.5 kg undergoes a quasi-static expansion which follows a relationship, p = a + b.v, where a and b are constants. The initial and final pressures are 1000 kPa and 200 kPa respectively and the corresponding volumes are 0.20 m³ and 1.20 m³. The specific internal energy of the gas is given by relation, (u = 1.5 pv – 85) kJ/kg where p is in kPa and v in m³/kg. Calculate the net heat transfer and the maximum internal energy of gas attained during expansion.

Sol. Given $m = 1.5$ kg, $p = a + bv$, $u = 1.5\,pv - 85$, $p_1 = 1000$ kPa, $p_2 = 200$ kPa, $v_1 = 0.20$ m³, $v_2 = 1.20$ m³.

Putting the initial and final conditions

$$u_1 = 1.5\,p_1v_1 - 85 \text{ and } u_2 = 1.5\,p_2v_2 - 85$$

$$u_2 - u_1 = 1.5\,(p_2v_2 - p_1v_1) \text{ kJ/kg}$$

If m be the mass of the gas, then

$$dU = U_2 - U_1 = 1.5\,m\,(p_2v_2 - p_1v_1)$$
$$= 1.5 \times 1.5\,(200 \times 1.20 - 1000 \times 0.20)$$
$$= \mathbf{90\ kJ} \quad \textbf{Ans.}$$

Given that $p = a + bv$

For the initial state of gas

$$1000 = a + b \times 0.20 \quad \text{...(i)}$$

For the final state of gas

$$200 = a + b \times 1.2 \quad \text{...(ii)}$$

Subtracting equation (ii) from equation (i), we get

$$1000 - 200 = 0.20\,b - 1.2\,b$$

or $$800 = -b \text{ or } b = -800$$

Substituting the value of b in equation (i),

$$1000 = a + (-800 \times 0.20) \text{ or } a = 1160$$

Work transfer, $$W_{1\text{-}2} = \int_{v_1}^{v_2} p\,dv = \int_{v_1}^{v_2} (a + bv)\,dv$$

$$= \left[av + \frac{bv^2}{2}\right]_{v_1}^{v_2} = a(v_2 - v_1) + b\left(\frac{v_2^2 - v_1^2}{2}\right)$$

$$= 1160(1.20 - 0.20) + (-800)\left[\frac{(1.20)^2 - (0.20)^2}{2}\right]$$

$$= 1160 - 560 = 600 \text{ kJ}$$

Heat transfer, $Q_{1\text{-}2} = W_{1\text{-}2} + dU = 600 + 90 =$ **690 kJ** **Ans.**

Prob.5. Air initially at 75 kPa pressure, 1000 K temperature and occupying a volume of 0.12 m³ is compressed isothermally until the volume is halved and subsequently it undergoes further compression at constant pressure till the volume is halved again. Sketch the processes on p-v diagram and find out the work transfer.

Sol. Given, $p_1 = 75$ kPa $= 75$ kN/m², $T_1 = 1000$ K, $v_1 = 0.12$ m³, $v_2 = v_1/2$ and $v_3 = v_2/2 = v_1/4$.

In p-v diagram, as shown in fig. 4.16 process 1-2 represents isothermal compression and process 2-3 represents compression at constant pressure.

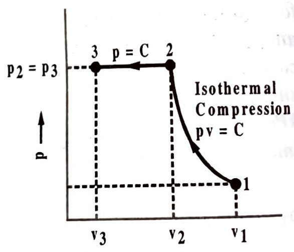


Fig. 4.16

We know that for isothermal compression 1-2,

$$p_1 v_1 = p_2 v_2$$

or $$p_2 = \frac{v_1}{v_2} \times p_1 = \frac{v_1}{v_{1/2}} \times 75 = 150 \text{ kN/m}^2$$

Work done,

$$W_{1\text{-}2} = 2.3\, p_1 v_1 \log r$$

$$W_{1\text{-}2} = 2.3\, p_1 v_1 \log \frac{v_1}{v_2} \quad (\because r = v_1/v_2 \text{ for compression})$$

$$= 2.3 \times 75 \times 0.12 \log \frac{v_1}{v_1/2} = 20.7 \log 2 = 6.2313 \text{ kJ}$$

For the constant pressure process 2-3,

$$\frac{v_2}{T_2} = \frac{v_3}{T_3} \text{ or } T_3 = \frac{v_3}{v_2} \times T_2$$

$$\therefore \quad T_3 = \frac{v_3}{v_2} \times T_1 \quad (\because T_2 = T_1 \text{ for isothermal compression process})$$

$$= \frac{v_1/4}{v_1/2} \times 1000 = 500 \text{ K}$$

Work done, $$W_{2\text{-}3} = p_2(v_2 - v_3) = 150 \times \left(\frac{v_1}{2} - \frac{v_1}{4}\right)$$

$$= 150 \times \left(\frac{0.12}{2} - \frac{0.12}{4}\right) = 4.5 \text{ kJ}$$

Therefore, the net work transfer,

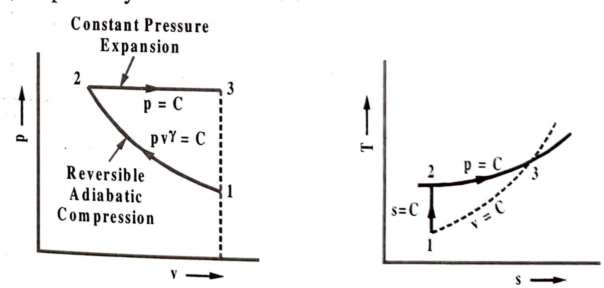
$$W_{net} = W_{1\text{-}2} + W_{2\text{-}3}$$
$$= 6.2313 + 4.5$$
$$= \mathbf{10.7313 \text{ kJ}}$$

Ans.

Prob.6. 0.5 kg of air is compressed reversibly and adiabatically from 80 kPa, 60°C to 0.4 MPa, and is then expanded at constant pressure to the original volume. Sketch these processes on p-v and T-s planes. Compute the heat transfer and work transfer for the whole path.

Sol. Given, $m = 0.5$ kg, $p_1 = 80$ kPa $= 80$ kN/m², $t_1 = 60$°C or $T_1 = 60 + 273 = 333$ K, $p_2 = 0.4$ MPa $= 400$ kN/m², $p_3 = p_2 = 400$ kN/m², $v_3 = v_1$.

This processes have been shown on p-v and T-s planes in fig. 4.17 (a) and (b) respectively.



(a) p-v Diagram *(b) T-s Diagram*

Fig. 4.17

From ideal gas equation,

$$p_1 v_1 = mRT_1$$

$$80 \times v_1 = 0.5 \times 0.287 \times 333 = 47.7855$$

$$(\because \text{For air, } R = 0.287 \text{ kJ/kg K})$$

$$\therefore \quad v_1 = 0.597 \text{ m}^3$$

For reversible adiabatic, i.e. isentropic compression process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_2}{333} = \left(\frac{400}{80}\right)^{\frac{1.4-1}{1.4}} = 1.5838 \qquad (\because \text{For air, } \gamma = 1.4)$$

$$\therefore \quad T_2 = 1.5838 \times 333 = 527.4 \text{ K}$$

Again for isentropic compression 1-2,

$$\left(\frac{v_2}{v_1}\right) = \frac{p_1}{p_2}$$

$$\left(\frac{v_2}{0.597}\right)^{1.4} = \frac{80}{400} = 0.2$$

$$\therefore \quad v_2 = 0.597 \times (0.2)^{1/1.4} = 0.189 \text{ m}^3$$

Now for constant pressure process 2-3,

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} = \frac{v_1}{v_2} \qquad (\because V_3 = V_1)$$

$$\frac{T_3}{527.4} = \frac{0.597}{0.189} = 3.16$$

$$\therefore \quad T_3 = 1666.6 \text{ K}$$

For isentropic compression, heat transfer = 0, thus total heat transfer,

$$Q = Q_{2\text{-}3} = mc_p(T_3 - T_2)$$

$$= 0.5 \times 1.005\ (1666.6 - 527.4)$$

$$(\because \text{For air, } c_p = 1.005 \text{ kJ/kg K})$$

$$= \mathbf{572.45\ kJ} \qquad \textbf{Ans.}$$

Total work transfer for the whole path,

$$W = W_{1\text{-}2} + W_{2\text{-}3}$$

$$= \frac{p_1 v_1 - p_2 v_2}{\gamma - 1} + p_2(v_3 - v_2)$$

$$= \frac{80 \times 0.597 - 400 \times 0.189}{1.4 - 1} + 400(0.597 - 0.189)$$

$$= -69.6 + 163.2 = \mathbf{93.6\ kJ} \qquad \textbf{Ans.}$$

CLASSIFICATION AND WORKING OF BOILERS, MOUNTINGS AND ACCESSORIES OF BOILERS, EFFICIENCY AND PERFORMANCE ANALYSIS

Q.23. State the classification of boilers. ***(R.G.P.V., June 2016)***

Or

Give classification of boilers on different basis. ***(R.G.P.V., Dec. 2012)***

Ans. Various criteria of boiler classification are discussed below –

(i) Tube Contents – According to the contents in the tube, the boilers are classified as –

(a) Fire tube boilers (b) Water tube boilers.

(a) Fire Tube Boilers – In fire tube boilers, the hot gases pass through the tubes and water surrounds them. Heat from hot flue gases is transferred to water which is converted into steam. The spent flue gases are then discharged to atmosphere through the chimney. The examples of fire tube boilers are Cochran, Lancashire, Cornish and Locomotive boilers.

(b) Water Tube Boilers – In water tube boilers, water flows inside the tubes and hot flue gases flow outside the tubes. The hot flue gases from the furnaces pass over the tubes and are discharged through the chimney. The water thus absorbs heat from the hot gases and evaporates in the form of steam. The examples of water tube boilers are Babcock and Wilcox boiler, Stirling boiler, etc.

(ii) Method of Firing – On the basis of method of firing, boilers are classified as –

(a) Internally fired boilers (b) Externally fired boilers.

(a) Internally Fired Boilers – In these boilers, the furnace region is provided inside the boiler shell and is completely surrounded by water cooled surfaces. Examples of the internally fired boilers are Locomotive, Lancashire and Scotch Marine boilers.

(b) Externally Fired Boilers – In these boilers, the furnace region is provided outside the boiler. Its furnace region is simple and easy to construct. Example of externally fired boiler is Babcock and Wilcox boiler.

(iii) Pressure of Steam – Boilers may be classified according to pressure as follows –

(a) Low pressure boilers (b) High pressure boilers.

(a) Low Pressure Boilers – A boiler which produces steam at a pressure lower than 80 bar is called a low pressure boiler. Examples are Cochran, Cornish, Lancashire and Locomotive boilers.

(b) High Pressure Boilers – A boiler which generates steam at a pressure higher than 80 bar is known as high pressure boiler. Examples are LaMont, Velox, Benson boilers.

(iv) Method of Circulation of Water – On the basis of method of circulation, boilers are classified as follows –

(a) Natural circulation (b) Forced circulation.

(a) Natural Circulation Boilers – In these type of boilers, circulation of water takes place by natural convection current produced by the application of heat. Examples are Lancashire, Locomotive, Babcock and Wilcox boilers.

(b) Forced Circulation Boilers – In these type of boilers, the circulation of water takes place by mechanical means (pumps). Examples are LaMont and Velox boilers.

(v) Nature of Service – Boilers are classified according to nature of service as follows –

(a) Mobile Boilers – The boilers which are fitted on vehicles that can move from place to place are called mobile boilers. Examples are Marine and Locomotive boilers.

(b) Portable Boilers – Boilers which can be readily dismantled and transported from one place to another are called portable boilers.

(c) Stationary Boilers – Boilers that are used for stationary plants are called stationary boilers.

(vi) Nature of Draught – Boilers may be classified as –

(a) Natural Draught Boilers – In this, the draught is produced by natural circulation of air or gas.

(b) Forced Draught Boilers – Here, the draught is produced by mechanical means such as fans etc.

(vii) Position of Shell – According to the position of the axis of the shell, the boilers are classified as horizontal and vertical boilers. In horizontal boilers, axis of the shell is horizontal and in vertical boilers, axis of the shell is vertical. Some horizontal boilers are Lancashire boiler, Locomotive boiler, Babcock and Wilcox boiler, etc. and the vertical boiler is Cochran boiler.

(viii) Number of Tubes – On this basis boiler may be classified as single tube boiler or multi-tube boiler.

A single tube boiler has only a single fire tube or water tube as in simple vertical boiler. While a multi-tube boiler has two or more fire tubes or water tubes. Locomotive boiler and Babcock and Wilcox boiler are multi-tube boilers.

Q.24. State the differences between the following boilers –

(i) Stationary and portable boiler

(ii) Forced circulation and natural circulation boiler

(iii) Externally and internally fired boiler

(iv) Single tube and multi-tube boiler.

Ans. Refer Q.23. **(R.G.P.V., Dec. 2013)**

Q.25. What is the difference between fire tube and water tube boilers ? Give example of each. **(R.G.P.V., Dec. 2006)**

Ans. The differences between fire tube and water tube boilers are given in the following table –

S.No.	Fire Tube Boiler	Water Tube Boiler
(i)	Hot flue gases flow inside the tubes while water surrounds the tubes.	Water flows inside the tubes while the hot flue gases surround the tubes.
(ii)	It has small capacity due to smaller heating surface area resulting in slow rate of steam generation. It is not suitable for steam power plants.	It has a wide range of capacity due to larger heating surface area resulting in high rate of steam generation. It is suitable for large power plants.
(iii)	Circulation is poor and thus there is every chance of a deposite of impurities on the heated surface. The construction is such that removal of impurities is difficult.	Circulation is greater, thus there are less chances of a deposite of impurities on the heated surface. The construction is such that impurities can be easily removed.
(iv)	An explosion, if it occurs, becomes a very serious problem in a fire tube boiler because of its large water capacity.	Because of the small drum size the water is uniformly spread in a large number of tubes thus the failure of one water tube does not cause any disastrous explosion.
(v)	It is less efficient.	It is highly efficient.
(vi)	Though it is suitable for rapid change in load, but large load fluctuations extending over long durations may damage the boiler.	It is suitable for large load fluctuations extending over long duration without danger to the boiler.
(vii)	The construction is simple, rigid and compact. Hence, the initial cost is less.	Design is complex. Hence, initial cost is high and it requires periodic examinations.
(viii)	Example – Cochran, Lancashire.	Examples – Babcock and Wilcox, Stirling.

Q.26. Explain construction and working of a Cochran boiler with the help of a neat skethch. ***(R.G.P.V., Dec. 2008)***

Ans. Cochran boiler is one of the best type of vertical multi-tubular boilers. Fig. 4.18 illustrates its design. It is made in different designs and sizes of evaporative capacities ranging from 150 to 3000 kg of water per hour and for working pressures upto 20 bar and is suitable for different types of fuels. Thermal efficiency of the Cochran boiler is about 70% with coal firing and about 75% with oil firing.

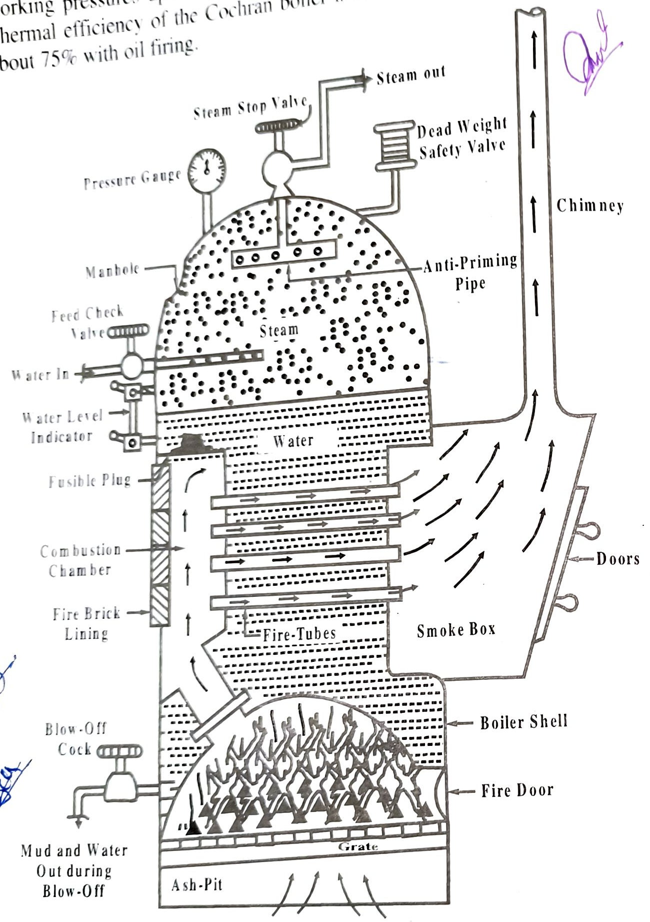


Fig. 4.18 Cochran Boiler

Cochran boiler consists of a cylindrical shell with its crown having a hemispherical shape. Such a shape of the crown plate gives enough strength

to withstand the bulging effect of the inside steam pressure. The fire-box is made in one piece and has no joints. The fire-box also has a crown of hemispherical shape. The hemispherical shape is advantageous for the absorption of the radiant heat from the furnace. The convection heat surfaces are provided by a large number of horizontal smoke tubes. The flue gases from the fire box enter through the small flue-pipe into the combustion chamber and strike on the boiler shell plate which forms the back of the combustion chamber. The back plate of the combustion chamber is lined with fire-bricks and can be conveniently dismantled and removed for cleaning of smoke tubes. The back plate directs the flue gases into the smoke tubes. The smoke tubes generally have 62.5 mm external diameter and are 165 in number. The gases after passing through the smoke tubes enter the smoke box and then to the chimney. Most of the smoke tubes are fixed in the vertical tube plates by being expanded in the holes but some of them are fixed by screwing into the holes. The screwed tubes form stays to the vertical tubes and prevent them from bulging out due to the inside steam pressure. A number of hand holes are provided around the outer shell for cleaning purposes. The flat top of the combustion chamber is strengthened by gusset stays.

Q.27. Draw a neat sketch of a Cochran boiler. State the function of any five important parts. ***(R.G.P.V., Dec. 2010)***

Ans. For sketch of a Cochran boiler, refer Q.26, fig. 4.18.

The Cochran boiler is provided with all required mountings. The function of each is briefly stated below –

(i) Pressure Gauge – This indicates the pressure of the steam inside the boiler.

(ii) Water Level Indicator – This indicates the water level in the boiler. The water level in the boiler should not fall below the prescribed level otherwise the boiler will be overheated and the tubes may burn out.

(iii) Safety Valve – Safety valve prevents increase of steam pressure in the boiler above its design pressure. When pressure exceeds the design pressure, the valve opens automatically and discharges the excess steam to the atmosphere.

(iv) Blow-off Cock – The water supplied to the boiler contains impurities like mud, sand and salt. During heating, they are deposited at the bottom of the boiler, and thus reduces its capacity and heat transfer rates. These are removed with the help of a blow-off cock, which is located at the bottom of the boiler.

(v) Steam Stop Valve – It regulates the flow of steam supply outside.

Q.28. Describe a locomotive boiler with neat sketches. Also show various mountings on it.

Ans. Locomotive boiler is a multitubluar, horizontal, internally fired and mobile boiler. The principal feature of this type of boiler is that it can produce

steam at a very high rate. Thus, it requires a large heating surface and a large grate area. Large heating surface is provided by providing a large number of fire tubes, and heat transfer rate is increased by creating a strong induced draught by means of a steam jet. It can generate 4500 to 7000 kg steam per hour at a pressure of about 17.5 bar.

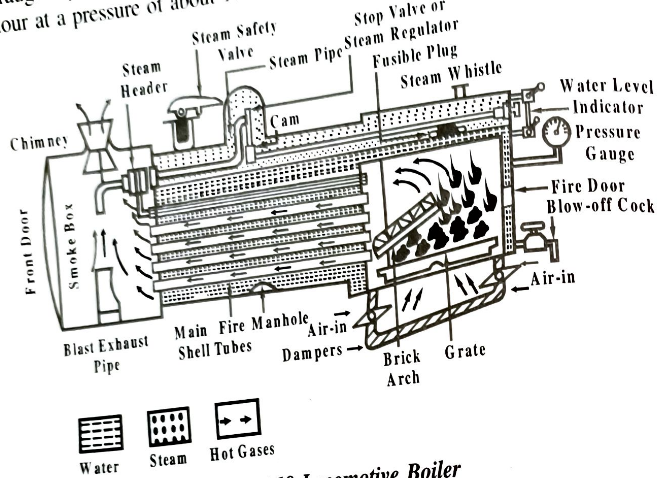


Fig. 4.19 Locomotive Boiler

A modern type of locomotive boiler as shown in fig. 4.19 consists of a cylindrical shell 1.5 m in diameter and of length 4 m. The cylindrical shell is fitted with a fire box at one end and a smoke box at the other end. The coal is fed into the fire box through fire doors and burns on grate. The flue gases so produced are deflected by a brick arch. The deflection of flue gases helps in proper and uniform heating of fire box, further it also prevents the flow of ash and coal particles with the gases. There are about 157 thin tubes or fire tubes of 47.5 mm diameter and 24 thick or superheater tubes of 130 mm diameter. Flue gases after passing through these tubes enters into smoke box and then lead to the atmosphere through chimney.

The steam generated is collected in the shell on top of the water surface. A dome shaped chamber known as steam dome, is fitted on top of the shell. The steam in the shell flows through a pipe mounted in the steam dome to the steam header, which is divided into two parts. One part of the steam header is known as saturated steam header and the other part is known as superheated steam header. Saturated steam from pipe enter into the saturated steam header and then passed to the superheater tubes. Superheated steam coming out of superheater tubes is collected in superheated header and then fed to the steam engine.

The height of the chimney of a locomotive has to be kept low in order to facilitate it to pass through the tunnels and bridges.

Q.29. With the help of a neat sketch, explain the working of a Babcock and Wilcox boiler.

(R.G.P.V., Dec. 2013)

Ans. Babcock and Wilcox boiler is a longitudinal drum, externally fired, water tube, natural circulation type of stationary boiler. Evaporative capacity of such boiler ranges from 20,000 to 40,000 kg/hr of steam and operating pressure from 11.5 to 17.5 bar are quite common.

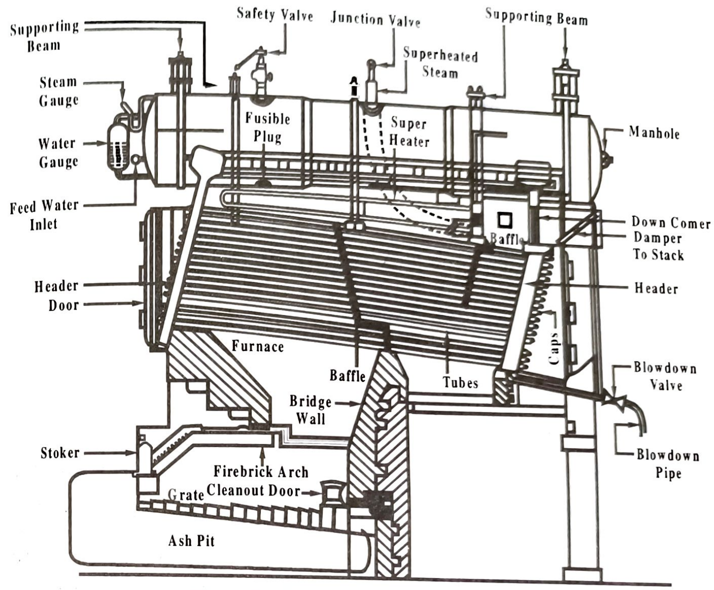


Fig. 4.20 Babcock and Wilcox Boiler

Construction – It consists of a high pressure drum mounted at the top. From each end of the drum, connections are made with the uptake header and downtake header. A large number of water tubes connects the uptake and downtake headers. The headers have a sinusoidal form. This sinusoidal form of headers arranges the water tubes such that they are staggered and this exposes the complete heating surface to flue gases. The heating surface of the unit is the outer surface of the tubes and half of the cylindrical surface of the water drum which is exposed to flue gases.

A mud box is attached to the bottom of the rear header (i.e., downtake header). The impurities and mud particles from the water are collected in the mud box and they are blown off from time to time by means of blow-off valve.

The furnace is arranged below the uptake header. Coal is fed to the grate through the fire door. Two firebrick baffles are arranged in such a manner that hot gases from the grate are compelled to move in the upward and downward directions.

Working – The hot gases from the furnace are forced to move upwards between the water tubes by fire brick baffles provided. They then move downwards between the tubes and then chimney or stack. The movement of the flue gases in this manner facilitates the heat transfer even to the highest part of the tubes. The feed water enters the front of the drum, passes to the back of the drum and then descends through the downcoming vertical tubes and enters the headers. The water then enters the water tubes, moves upwards through the inclined tubes and finally rises through the front riser tubes to the drum. The water circulation occurs due to difference of density of water which in turn is due to difference of temperature in the front and back parts of the furnace. Thus, a thermosiphon effect is produced which results in continuous and rapid circulation of water.

Q.30. Explain the working of a water tube boiler with the help of a neat sketch. ***(R.G.P.V., June 2012)***

Ans. A La-Mont boiler as shown in fig. 4.21 is a forced circulation, water tube boiler. In this boiler water circulates in tubes surrounded by steam.

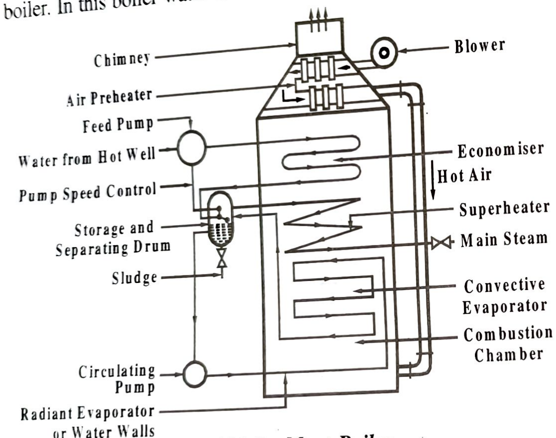


Fig. 4.21 La-Mont Boiler

The feed water from the hot well is supplied through an economiser to a separation and storage drum which contains a feed regulator that controls the speed of the feed pump. Since the economiser is placed in the boiler at a place from where hot combustion gases pass, the economiser supplies sensible heat to the feed water from the boiler drum flows by gravity to a circulating pump, which discharges into a distributing header. Water from the distributing header flows through long, small diameter boiler tubes located in the wall and roof of the furnace to the drum where steam is separated and water returns to the pump. Orifice located at inlet to each circuit on the distributing header correctly proportions the water among the many parallel circuits, so that each receives its

proper amount. The circulating pump rises the water pressure to about 3.5 bar above the drum pressure to overcome the resistance to the orifices and the long circuit of small diameter tubing. From the drum a centrifugal pump circulates about 8 to 10 times the quantity of water evaporated. This large quantity of water circulated prevents the tubes from being overheated. The circulating pump passes water first to radiant evaporator or water wall. Then steam and water pass to convective evaporator and again to the drum, where the moisture is separated. The steam is led to the tubes in which the steam gets superheated.

La-Mont boiler generates 40 to 50 tonnes of superheated steam per hour at 500°C and 125 bar pressure.

La-Mont boiler has following advantages –

(i) Flexibility of design

(ii) Compactness and small size of drum.

It generally resembles a natural circulation boiler. Formation and attachment of bubbles on the inner surfaces of the heating tubes reduces the heat flow and steam generation as it offers high thermal resistance than water film.

Q.31. How boilers are classified ? Write down few names of mountings and accessories of a boiler. ***(R.G.P.V., June 2014)***

Ans. **Boiler Classification –** Refer Q.23.

Mountings and Accessories – Boiler mountings are the devices, which are necessary for the safe and satisfactory operation of the steam boiler. Mountings are either installed or mounted on the body of boiler itself. These mountings form an integral part of the boiler and a boiler cannot work safely without these mountings.

The commonly used boiler mountings are given as follows –

(i) Water level indicator (ii) Pressure gauge

(iii) Safety valves

(a) Lever safety valve

(b) Dead weight safety valve

(c) High steam and low water safety valve

(d) Spring loaded safety valve.

(iv) Steam stop valve (v) Blow-off cock

(vi) Feed check valve (vii) Fusible plug.

Boiler accessories are the devices which are used as integral parts of a boiler, and help to increase the overall efficiency of the plant.

Boiler accessories are given as follows –

(i) Feed pump (ii) Injector

(iii) Economiser (iv) Superheater

(v) Air preheater.

Q.32. *What is the difference between the boiler mountings and accessories ?* **(R.G.P.V., Dec. 2017)**

Or

Differentiate clearly between mountings and accessories of a boiler with suitable examples. **(R.G.P.V., Sept. 2009)**

Or

Differentiate between the boiler mounting and accessory. **(R.G.P.V., Dec. 2011)**

Ans. **Differences between Boiler Mountings and Accessories –**

S.No.	Mountings	Accessories
(i)	Boiler mountings are primarily intended for safety of the boiler.	Boiler accessories are used to increase the efficiency of a boiler.
(ii)	A boiler cannot work without mountings.	A boiler can work without accessories.
(iii)	Mountings are mounted on the body of the boiler itself.	Accessories are installed with the boilers to increase their efficiency.
(iv)	Examples are pressure gauge, safety valves, fusible plug, etc.	Examples are feed pump, injector, economiser, etc.

Q.33. Name some commonly used boiler mounting and give their functions.

Ans. Some commonly used boiler mounting and their function are tabulated below –

S.No.	Mounting	Function
(i)	Water level indicator	Shows working level of water in the boiler.
(ii)	Pressure gauge	Shows working pressure of boiler.
(iii)	Safety valves	Prevent boiler pressure to rise beyond its safe value.
(iv)	Dual function safety valves (a) High steam low water safety valve (b) Low water high water safety valve	 Allows escape of steam in case of unsafe high pressure or unsafe water level. Whistles by blowing steam in case of unsafe low or high water level in the drum.
(v)	Steam stop valve	Regulates the amount of outgoing steam.
(vi)	Blow-off cock	Allow to drain water from boiler.
(vii)	Feed check valve	Checks the amount of feed water going to the boiler and does not allow its return.
(viii)	Fusible plug	Stops the boiler, if its heating surface gets overheated due to low water level.

Q.34. Name boiler mountings and explain one of them. **(R.G.P.V., Dec. 2014)**

Ans. For name of boiler mountings, refer Q.31.

Safety Valve – The main function of a safety valve is to prevent an increase in the steam pressure in the boiler from exceeding the design pressure for the boiler. When there is a sudden drop in steam requirements, the steam pressure in the boiler will increase. In such case, safety valve opens automatically and allows escape of the excess steam to the atmosphere, thus the pressure of the steam in drum falls below the critical value. The escape of steam makes a audio noise to warn the boiler attendant. When pressure falls below the unsafe level, the valve closes automatically without interrupting the boiler operation.

Q.35. Write short note on – Fusible plug.

Ans. Function of the fusible plug is to protect the fire box crown plate, or the fire tube from burning when the level of the water in the boiler shell falls abnormally low.

The fusible plug as shown in fig. 4.22 consists of a hollow gun metal body screwed into the fire box crown. The body has hexagonal flange to tighten it into the shell. There is another solid plug made of copper with conical top and rounded bottom. Fusible metal holds this conical copper plug and the gun metal plug together due to depressions provided at the mating surfaces.

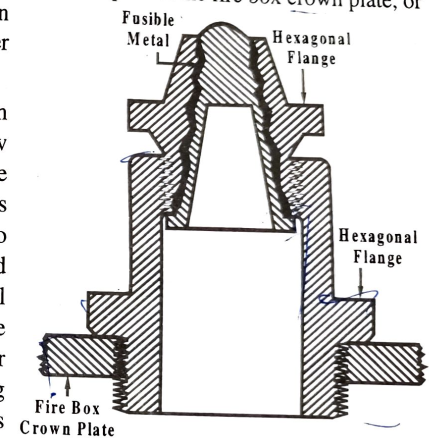


Fig. 4.22 Fusible Plug

This plug under normal conditions is covered with water in the boiler which keeps the temperature of the fusible metal below its melting point. When the water level falls low enough to uncover the top of the plug, the fusible metal quickly melts, the plug drops out and the opening so made allows the steam to rush into the furnace. The steam, thus, puts out the fire or gives warning that the crown of furnace is in danger of being over-heated.

Q.36. Explain with sketches the working of following boiler mountings –

(i) Pressure gauge (ii) Steam stop valve.

Ans. (i) Pressure Gauge – Each boiler must have a steam pressure gauge to show or read the pressure of steam in the boiler. It is fixed in front of

the boiler. The pressure gauges generally used are of Bourdon type. Its dial is graduated to read the pressure in kPa or kN/m^2 above atmospheric pressure.

A Bourdon pressure gauge is shown in fig. 4.23.

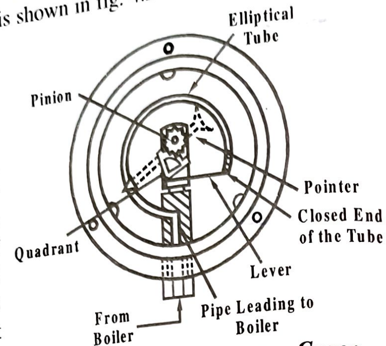


Fig. 4.23 Bourdon Pressure Gauge

The essential feature of a Bourdon pressure gauge is the elliptical spring tube which is made of bronze and is solid drawn. The one end of the tube is closed by a plug and the other end is connected to steam space of the boiler. The closed end of tube is connected to a toothed quadrant with the help of links and pins. The toothed quadrant meshes with a small pinion fitted on the central spindle. When steam pressure is supplied to interior of the elliptical tube, it tends to assume a circular cross-section, but before the tube can do so it must straighten out. This tendency of the tube moves the free end, turning the spindle by lever and gearing (pinion and quadrant), and causing the pointer to move and register the pressure on a graduated dial.

The Bourdon pressure gauge is connected to the boiler through U-tube siphon which is connected to the steam space of the boiler.

The movement of the free end of the tube is proportional to the difference between external pressure and internal pressure on the tube. Since, the outside pressure on the tube is atmospheric therefore the movement of the free end of the tube is a measure of the boiler steam pressure above atmospheric pressure.

The Bourdon pressure gauge should be graduated to read atleast $1\frac{1}{2}$ times the set pressure of safety valve.

(ii) ***Steam Stop Valve –*** A steam stop valve is used to regulate the flow of steam from boiler to the engine as per the requirement and shut-off the steam flow when not required. A commonly used steam stop valve is shown in fig. 4.24.

Main body of valve is made of cast iron. Valve disc is connected with a spindle by nut. The valve, valve seat and nut through which valve works are made of brass for smooth working. The spindle passes through a gland and stuffing box fixed in the cover of the valve body. The upper portion of the spindle is threaded and passes through a nut in a cross head or yoke carried by two pillars, which are screwed into the cover of the valve body. By turning the hand wheel fitted on the spindle, the valve spindle can be raised or lowered.

In locomotive boiler, hand wheel is operated by a regulator, which is placed inside the boiler and operated by driver.

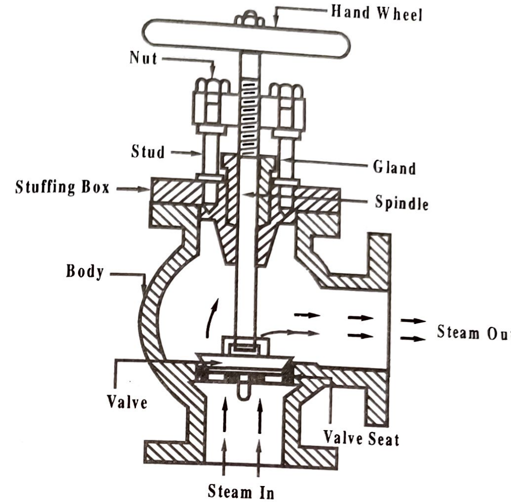


Fig. 4.24 Steam Stop Valve

Q.37. Enlist commonly used boiler accessories and give their functions.

Ans. Various boiler accessories and their functions are given below –

S.No.	Accessory	Function
(i)	Economiser	Preheating the feed water by utilising the heat of flue gases.
(ii)	Superheater	Increasing the temperature of steam at constant pressure beyond saturation temperature.
(iii)	Air preheater	Preheat the fresh air by utilising the heat of flue gases.
(iv)	Antipriming devices	Filter out moisture from outgoing steam.
(v)	Steam injector	Lifts and forces the feed water into the boiler.

Q.38. What do you understand by the term boiler performance?

Ans. The performance of a boiler is judged by calculating quantity of heat produced by utilising the heat of combustion of fuel. Steam production rate and its quality (wet, saturated or superheated) varies with different feed water temperature, different boiler pressure, different saturation temperature. Under such different conditions, it is very difficult to compare two boilers. Thus, efforts have been made to provide the common basis for comparing the performance of two or more boilers. The standard conditions adopted are as feed water temperature of 100°C and working pressure is 1.01325 bar (1 atm)

and the quantity of heat required to produce dry and saturated steam is 2257 kJ/kg and it is considered standard evaporation unit.

Depending upon the operating conditions any one of the following terms or combination of them may be used to describe the performance of the boiler –

(i) Equivalent evaporation (ii) Boiler efficiency
(iii) Overall efficiency (iv) Combustion rate
(v) Combustion space (vi) Heat liberated.

Q.39. What do you mean by evaporative capacity of a boiler ?

Ans. The evaporative capacity of a boiler is defined as the quantity of steam generated in kg per unit time at full load. It is expressed on the basis of grate area or furnace volume or fuel burnt. Mathematically,

$$\text{Evaporative capacity} = \frac{\text{Total steam generated}}{\text{Area of grate}} = \frac{m_s}{A}\ \text{kg/m}^2/\text{hr}$$

$$= \frac{\text{Total steam generated}}{\text{Volume of furnace}} = \frac{m_s}{v_f}\ \text{kg/m}^3/\text{hr}$$

$$= \frac{\text{Total steam generated}}{\text{Total fuel burnt}} = \frac{m_s}{m_f}\ \text{kg/kg of fuel}$$

(R.G.P.V., Dec. 2011)

Q.40. Define boiler efficiency.

Ans. Boiler efficiency may be defined as the ratio of heat actually used in producing the steam to the heat liberated in the furnace. It is also known as thermal efficiency of the boiler. Mathematically,

Boiler efficiency or thermal efficiency

$$= \frac{\text{Heat actually used in producing steam}}{\text{Heat liberated in the furnace}}$$

$$\eta = \frac{m_e(h - h_{f_1})}{\text{C.V.}}$$

where, m_e = Mass of water actually evaporated or actual evaporation in kg /kg of fuel.

C.V. = Calorific value of fuel in kJ/ kg of fuel.

Let, m_s = Total mass of water evaporated into steam in kg.

m_f = Mass of fuel used in kg.

$$\therefore \quad m_e = \frac{m_s}{m_f}\ \text{kg / kg of fuel.}$$

$$\text{Boiler efficiency, } \eta = \frac{m_s(h - h_{f1})}{m_f \times \text{C.V.}}$$

If a boiler consisting of an economiser and superheater, is considered to be a single unit, then the efficiency is known as overall efficiency of the boiler.

Q.41. "Equivalent evaporation from and at 100°C". Explain the meaning of the term and give the reason for its use in the context of boiler performance.

(R.G.P.V., Dec. 2015)

Or

What is equivalent evaporation ?

(R.G.P.V., June 2015)

Ans. The evaporative capacities of two boilers cannot be compared unless both the boilers have the same feed water temperature, working pressure, fuel and final condition of steam. In actual practice, the feed water temperature and working pressure varies considerably. Thus, in order to compare evaporative capacities of two boilers it is necessary to fix some common standards. Thus, a more logical term known as equivalent evaporation has been defined to compare two boilers.

Equivalent Evaporation is the amount of water evaporated at 100°C and formed into dry and saturated steam at 100°C at normal atmospheric pressure. It is usually, written as "from and at 100°C ". The quantity of heat supplied by the boiler to each kg of steam is 2257 kJ under the above mentioned condition.

Let us assume that a boiler generates m_e kg of steam per hour or kg/kg of fuel burnt.

Let, t_1 = Temperature of feed water in °C

h_{f1} = Enthalpy or sensible heat of feed water in kJ /kg of steam corresponding to t_1 °C (from steam tables)

h_{fg} = Specific enthalpy of evaporation at standard atmospheric pressure

h = Enthalpy or total heat of steam in kJ/kg of steam corresponding to a given working pressure (from steam tables).

Heat required to evaporate one kg of water = $h - h_{f1}$

Total heat required to evaporate m_e kg of water = $m_e(h - h_{f1})$

Equivalent evaporation 'from and at 100°C'

$$E = \frac{m_e(h - h_{f1})}{2257} = F_e . m_e$$

where $F_e = \dfrac{h - h_{f1}}{2257}$ is known as ***factor of evaporation.*** Its value is always greater than unity for all boilers.

NUMERICAL PROBLEMS

Prob.7. In a boiler a fuel with a lower calorific value of 37500 kJ is burnt completely at air-fuel ratio of 25 : 1. If whole heat of combustion is received by the products of combustion and their average specific heat is 1.15 kJ/kg K, calculate the maximum temperature attained in the furnace of the boiler. Take room temperature as 40°C and neglect ash contents.

(R.G.P.V., March/April 2010)

Sol. Given, L.C.V. of fuel = 37500 kJ, A : F = 25 : 1, c_{pg} = 1.15 kJ/kg K, t_1 = 40°C or T_1 = 40 + 273 = 313 K.

Since the whole heat is taken by gases, therefore,

Heat of combustion = Heat of gases

$$1 \times 37500 = m_g \times c_{pg} \times (T_2 - T_1)$$

$$= (25 + 1) \times 1.15\,(T_2 - 313)$$

$$\therefore \quad T_2 = \frac{1 \times 37500}{26 \times 1.15} + 313 = 1567.18 \text{ K}$$

i.e., $T_2 = 1567.18$ K or 1294.18°C

Hence, the maximum temperature attained in the furnace of boiler is

$$T_2 = \mathbf{1294.18°C}$$ **Ans.**

Prob.8. Calculate the equivalent evaporation of boiler per kg of coal fired, if the boiler produces 50000 kg of wet steam per hour with a dryness fraction of 0.95 and operating at 10 bar. The coal burnt per hour in furnace is 5500 kg and feed water temperature is 40°C. ***(R.G.P.V., Dec. 2010)***

Sol. Given, $m_s = 50000$ kg, $x = 0.95$, $p = 10$ bar, $m_f = 5500$ kg, $t_w = 40$°C.

Mass of water evaporated per kg of coal,

$$m_e = \frac{m_s}{m_f} = \frac{50000}{5500} = 9.09 \text{ kg}$$

From steam tables corresponding to a feed water temperature of 40°C,

$$h_{f_1} = 167.5 \text{ kJ/kg}$$

From steam tables corresponding to a pressure of 10 bar,

$$h_f = 762.6 \text{ kJ/kg}, \; h_{fg} = 2013.6 \text{ kJ/kg}$$

Enthalpy of steam, $h = h_f + xh_{fg}$

$$= 762.6 + 0.95 \times 2013.6 = 2675.52 \text{ kJ/kg}$$

Equivalent evaporation per kg of coal fired,

$$E = \frac{m_e(h - h_{f_1})}{2257} = \frac{9.09(2675.52 - 167.5)}{2257} = \mathbf{10.1 \text{ kg/kg of coal}}$$ **Ans.**

Prob.9. In a boiler trial the following obervations are made –

Feed water temperature = 40° C
Boiler pressure = 15 bar
Dryness fraction of steam = 0.85
Coal consumption = 450 kg/hr
Feed water supplied = 3500 kg/hr
C.V. of coal = 40000 kJ/kg.

Calculate the evaporation factor and equivalent evaporation at 100°C in kg/kg of coal. ***(R.G.P.V., Dec. 2014)***

Sol. Given, $t_w = 40$°C, $p = 15$ bar, $x = 0.85$, $m_f = 450$ kg/hr, $m_s = 3500$ kg/hr, C.V. of coal = 40000 kJ/kg.

Mass of water evaporated per kg of coal consumed,

$$m_e = \frac{m_s}{m_f} = \frac{3500}{450} = 7.78 \text{ kg}$$

From steam tables corresponding to a feed water temperature of 40 °C,

$$h_{f_1} = 167.5 \text{ kJ/kg}$$

Again from steam tables at 15 bar,

$$h_f = 844.6 \text{ kJ/kg}, \; h_{fg} = 1945.3 \text{ kJ/kg}$$

Enthalpy of 1 kg of wet steam generated in boiler

$$h = h_f + xh_{fg}$$

$$= 844.6 + 0.85 \times 1945.3 = 2498.1 \text{ kJ/kg}$$

Evaporation factor,

$$F_e = \frac{h - h_{f_1}}{2257} = \frac{2498.1 - 167.5}{2257} = \mathbf{1.033}$$ **Ans.**

Equivalent evaporation from and at 100°C

$$E = F_e . m_e$$

$$= 1.033 \times 7.78 = \mathbf{8.04 \text{ kg/kg of coal}}$$ **Ans.**

Prob.10. 5000 kg of steam is produced per hour at a pressure of 7 bar in a boiler. The temperature of feed water is 40°C. The dryness fraction of steam at exit is 0.98. The mass of coal burnt per hour is 700 kg and calorific value of coal is 31000 kJ/kg.

Determine the equivalent evaporation and boiler efficiency.

(R.G.P.V., June 2015)

Sol. Given, $m_s = 5000$ kg/hour, $p = 7$ bar, $t_w = 40$°C, $x = 0.98$, $m_f = 700$ kg/hour, C.V. = 31000 kJ/kg.

Mass of water evaporated per kg of coal consumed,

$$m_e = \frac{m_s}{m_f} = \frac{5000}{700} = 7.14 \text{ kg}$$

From steam tables corresponding to a feed water temperature of 40°C.

$$h_{f_1} = 167.5 \text{ kJ/kg}$$

Again from steam tables at 7 bar,

$$h_f = 697.1 \text{ kJ/kg}, \; h_{fg} = 2064.9 \text{ kJ/kg}$$

Enthalpy of 1 kg of wet steam generated in boiler,

$$h = h_f + xh_{fg}$$

$$= 697.1 + 0.98 \times 2064.9 = 2720.7 \text{ kJ/kg}$$

Now equivalent evaporation from and at 100°C,

$$E = \frac{m_e(h - h_{f_1})}{2257} = \frac{7.14(2720.7 - 167.5)}{2257}$$

$$= \mathbf{8.08 \text{ kg/kg of coal}}$$ **Ans.**

and thermal efficiency of boiler.

$$\eta = \frac{m_e(h - h_{f_1})}{C.V.}$$

$$= \frac{7.14(2720.7 - 167.5)}{31000}$$

$$= 0.588 \text{ or } \mathbf{58.8\%} \qquad \textbf{Ans.}$$

Prob.11. The following observations were made in a boiler –

Coal used	*= 200 kg/hr*
Mass of steam	*= 2000 kg/hr*
Steam pressure	*= 11.2 bar*
Dryness fraction	*= 0.95*
Feed water temperature	*= 32.15°C*
Calorific value of coal	*= 28800 kJ/kg.*

Calculate the equivalent evaporation from and at 100°C per kg of coal and boiler efficiency. ***(R.G.P.V., June 2014)***

Sol. This problem can be solved in a similar way as discussed in Prob.10.

Prob.12. In a boiler test 1250 kg of coal is consumed in 24 hours. The mass of water evaporated is 13000 kg and the mean effective pressure is 7 bar. The feed water temperature was 40°C, heating value of coal is 30000 kJ/kg. The enthalpy of 1 kg of steam at 7 bar is 2570.7 kJ. Determine –

(i) Equivalent evaporation per kg of coal

(ii) Efficiency of boiler.

(R.G.P.V., Dec. 2017)

Sol. Given. m_f = 1250 kg, m_s = 13000 kg, p = 7 bar, t_w = 40°C, C.V. of coal = 30000 kJ/kg, h = 2570.7 kJ/kg.

Mass of water evaporated per kg of coal consumed,

$$m_e = \frac{m_s}{m_f} = \frac{13000}{1250} = 10.4 \text{ kg}$$

From steam tables corresponding to a feed water temperature of 40°C,

h_{f_1} = 167.5 kJ/kg

(i) Equivalent evaporation

Equivalent evaporation per kg of coal fired,

$$E = \frac{m_e(h - h_{f_1})}{2257}$$

$$= \frac{10.4(2570.7 - 167.5)}{2257} = \mathbf{11.07 \text{ kg/kg of coal}} \qquad \textbf{Ans.}$$

(ii) Efficiency of boiler

Thermal efficiency of boiler.

$$\eta = \frac{m_e(h - h_{f_1})}{C.V.} = \frac{10.4(2570.7 - 167.5)}{30000}$$

$$= 0.833 \text{ or } \mathbf{83.3\%} \qquad \textbf{Ans.}$$

Prob.13. A coal fired boiler plant consumes 400 kg of coal per hour. The boiler evaporates 3200 kg of water at 44.5°C into superheated steam at a pressure of 12 bar and 274.5°C. If the calorific value of fuel is 32760 kJ/kg of coal, determine –

(i) Equivalent evaporation ***(ii) Thermal efficiency of boiler.***

(R.G.P.V., Dec. 2012)

Sol. Given, m_f = 400 kg/hr, m_s = 3200 kg/hr, t_w = 44.5°C, p = 12 bar, t_{sup} = 274.5°C, C.V. of coal = 32760 kJ/kg.

Mass of water evaporated per kg of coal,

$$m_e = \frac{m_s}{m_f} = \frac{3200}{400} = 8 \text{ kg}$$

From steam tables corresponding to a temperature of 44.5°C

$$h_{f_1} = 186.3 \text{ kJ/kg}$$

Again from steam tables, at 12 bar

$$h_g = 2782.7 \text{ kJ/kg}, \; t = 188°C$$

We know that, enthalpy or total heat of 1 kg of superheated steam

$$h_{sup} = h_g + c_p(t_{sup} - t) \qquad (\text{Let } c_p = 2.1 \text{ kJ/kg K})$$

$$= 2782.7 + 2.1\,(274.5 - 188) = 2964.35 \text{ kJ/kg}$$

(i) Equivalent evaporation

Equivalent evaporation per kg of coal fired,

$$E = \frac{m_e(h - h_{f_1})}{2257}$$

$$= \frac{8(2964.35 - 186.3)}{2257} = \mathbf{9.85 \text{ kg/kg of coal Ans.}}$$

(ii) Thermal efficiency of boiler

Thermal efficiency of the boiler,

$$\eta = \frac{m_e(h - h_{f_1})}{C.V.}$$

$$= \frac{8(2964.35 - 186.3)}{32760} = 0.6784 \text{ or } \mathbf{67.84\%} \textbf{ Ans.}$$

Prob.14. *Calculate the equivalent evaporation from and at 100°C for a boiler, which receives water at 60°C and produces steam at 1.5 MPa and 300°C. The steam generation rate is 16000 kg/hr. Coal is burnt at the rate of 1800 kg/hr. The calorific value of coal is 34750 kJ/kg. Also calculate the thermal efficiency of boiler.* **(R.G.P.V., June 2011)**

Sol. This problem can be solved in a similar way as discussed in Prob.13.

NATURAL AND ARTIFICIAL DRAUGHT

Q.42. What is draught ? Write various types. **(R.G.P.V., Dec. 2016)**

Ans. Hot flue gases produced in the boiler due to combustion of fuel, need to be removed regularly. The pressure required to remove the gases is termed as boiler draught. The boiler draught or simply known as draught can be classified as –

- Draught
  - Natural or Chimney Draught
  - Artificial Draught
    - Steam Jet Draught
      - Induced Draught
      - Forced Draught
    - Mechanical Draught
      - Induced Fan Draught
      - Balanced Draught
      - Forced Fan Draught

The draught produced by the boiler chimney is termed as natural draught or chimney draught. It is produced due to difference of densities between the hot gases inside the chimney and the cold atmospheric air outside it. Large steam generators which need to handle a tremendous volume of gases, require artificial draught. Artificial draught is produced by means of a steam jet or a fan.

Q.43. Explain the natural draught. **(R.G.P.V., June 2008)**

Ans. Draught produced by the boiler chimney is termed as natural draught or chimney draught. It is produced due to difference of densities between the hot gases inside the chimney and the cold atmospheric air outside it.

Refer fig. 4.25, consider a case when furnace is not fired. The pressure at points, A,B,C,D and E will be the atmospheric pressure (say p_1). Pressure at all the points in a horizontal line passing through top of the chimney a,b,c,d and e will also be the same say p_2. This pressure p_2 is equal to the atmospheric pressure column of cold atmospheric air above grate level. Now, if furnace is fired the chimney will get filled with hot gases the pressure at top of the chimney and at grate level remain unaltered. But at base of the chimney, the pressure will be the sum of pressure p_2 and column of hot gases in the chimney. Since cold atmospheric air is heavier than the hot gases, thus

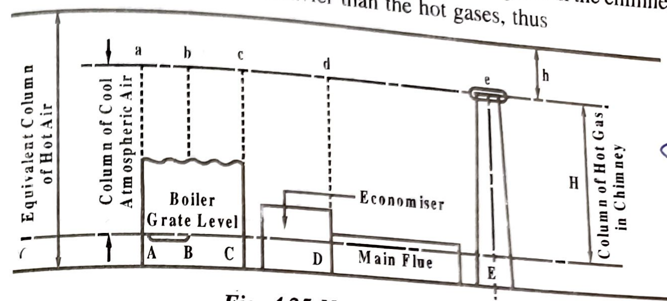


Fig. 4.25 Natural Draught

Pressure at the grate due to column of cold atmospheric air > Pressure at the base of chimney due to column of hot flue gases.

This difference in static pressure at the grate level and the base of chimney, is known as static draught. It is equivalent to height h of the hot gas column expressed in mm of water. Due to this draught the air will flow from the ash pit through the grate and via the economiser and the flue to the chimney base.

Q.44. What are the limitations of chimney draught ? **(R.G.P.V., June 2005)**

Ans. Limitations of the chimney draught are given as follows –

(i) Chimney draught is not suitable when the rate of fuel burning required is to be very high.

(ii) It is costlier than artificial draught.

(iii) It cannot be controlled because it depends on the atmospheric temperature.

(iv) The flow of air through the grate and furnace is not uniform.

(v) It produces comparatively less draught.

(vi) Rate of combustion is low.

(vii) The air flow cannot be regulated according to the changing requirements.

(viii) It is affected considerably by the atmospheric temperature.

(ix) Fuel consumption is more. About 15% more fuel is consumed for the same amount of work.

Q.45. Obtain an expression for draught produced in mm of water column when the discharge is maximum. **(R.G.P.V., Dec. 2015)**

Ans. The natural draught is produced by means of a chimney. Since the amount of draught depends upon the height of chimney therefore its height should be such that it can produce a sufficient draught. A relationship between the height of a chimney and the draught it produces in terms of temperature of outside air and the average flue gas temperature, can be derived in the following manner –

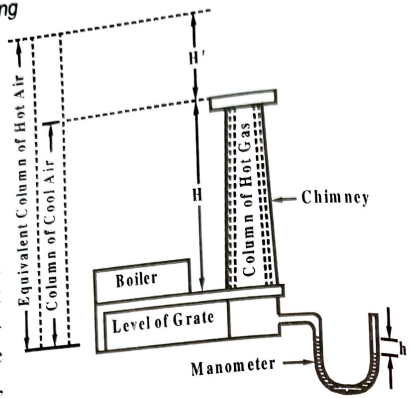


Fig. 4.26 Height of Chimney

Let, H = Height of chimney above the fire grate in metres

h = Draught required in terms of mm of water

T_a = Absolute temperature of air outside the chimney in K

T_g = Absolute temperature of the flue gas inside the chimney in K

v_a = Volume of outside air at temperature T_a in m^3/kg of fuel

v_g = Volume of flue gases inside the chimney at temperature T_g in m^3/kg of fuel

m = Mass of air actually used in kg /kg of fuel

m + 1 = Mass of flue gases in kg/kg of fuel.

Let us find the volume of outside air per kg of fuel at N.T.P. (i.e., at 0°C and 1.013 bar)

Let, v_0 = Volume of air at 0°C.

∴ Absolute temperature, $T_0 = 0°C + 273 = 273$ K

Atmospheric pressure, $p_0 = 1.013 \text{ bar} = 1.013 \times 10^5 \text{ N/m}^2$ $\quad (\because 1 \text{ bar} = 10^5 \text{ N/m}^2)$

We know that $\quad pv = mRT$

$$\therefore \quad v_0 = \frac{mRT_0}{p_0} = \frac{m \times 287 \times 273}{1.013 \times 10^5}$$

$$= 0.7734m \text{ m}^3\text{/kg of fuel}$$

$(\because$ For air, R = 287 J/kg K)

Volume of outside air at T_a K,

$$v_a = \frac{v_0 T_a}{T_0} \qquad \left[\because \frac{v_0}{T_0} = \frac{v_a}{T_a}\right]$$

$$= \frac{0.7734m \times T_a}{273} = \frac{m \times T_a}{353} \text{ m}^3\text{/kg of fuel}$$

Density of outside air at T_a K

$$\rho_a = \frac{m}{v_a} = \frac{m}{\frac{mT_a}{353}} = \frac{353}{T_a} \text{ kg/m}^3 \qquad \left(\because \text{Density} = \frac{\text{Mass}}{\text{Volume}}\right)$$

∴ Pressure due to a similar column of outside (cold) air,

$$p_a = \text{Density} \times \text{height} \times g$$

$$= \rho_a H g = \frac{353}{T_a} \times H \times 9.81 = \frac{3463H}{T_a} \text{ N/m}^2$$

According to Avogadro's law, the flue gas at N.T.P. occupies the same volume as that of air used at N.T.P.

Volume of flue gases at 0°C = 0.7734m m^3/kg of fuel.

Volume of flue gases at T_g K,

$$v_g = \frac{mT_g}{353} \text{ m}^3\text{/kg of fuel}$$

Density of flue gases at T_g K,

$$\rho_g = \frac{m+1}{\frac{mT_g}{353}} = \frac{353(m+1)}{mT_g} \text{ kg/m}^3$$

Pressure due to column of hot gases at the base of chimney,

$$p_g = \rho_g H g$$

$$= \frac{353(m+1)H \times 9.81}{mT_g} = \frac{3463(m+1)H}{mT_g} \text{ N/m}^2$$

The draught pressure is due to the pressure difference between the hot column of gas in the chimney and a similar column of cold air outside the chimney. Therefore draught pressure,

$$p = p_a - p_g$$

$$p = \frac{3463H}{T_a} - \frac{3463(m+1)H}{mT_g}$$

$$p = 3463H\left[\frac{1}{T_a} - \frac{(m+1)}{mT_g}\right] \text{ N/m}^2 \qquad \text{....(i)}$$

$$h = 353H\left[\frac{1}{T_a} - \frac{(m+1)}{mT_g}\right] \text{ mm of water} \qquad \text{...(ii)}$$

$$\left[\text{Since, } 1 \text{ N/m}^2 = \frac{1}{9.81} = 0.101937 \text{ mm of water}\right]$$

Equation (ii) gives the draught produced in mm of water, when the discharge is maximum. This gives the theoretical value of the draught also known as static draught. The actual value of draught is less than the theoretical value.

Q.46. Derive an expression for chimney height.

Ans. As derived in Q.45, draught pressure,

$$p = 3463H\left[\frac{1}{T_a} - \frac{(m+1)}{mT_g}\right] N/m^2 \quad \ldots(i)$$

If H' is the height in metres of the hot gas column which would produce the draught pressure p, then

$$p = \text{Density} \times H' \times g$$

$$= \frac{353(m+1)H' \times 9.81}{mT_g} = \frac{3463(m+1)H'}{mT_g} N/m^2$$

Substituting the value of p in equation (i), we get

$$\frac{3463(m+1)H'}{mT_g} = 3463H\left(\frac{1}{T_a} - \frac{m+1}{mT_g}\right)$$

$$H' = H\left[\left(\frac{m}{m+1} \times \frac{T_g}{T_a}\right) - 1\right] \text{ metres}$$

The velocity of flue gases through the chimney under a static draught of H' metres is given by

$$V = \sqrt{2gH'} = 4.43\sqrt{H'} \quad \text{(neglecting friction)}$$

Q.47. Differentiate between natural and artificial draughts. **(R.G.P.V., Feb. 2010)**

Ans. Differences between natural and artifical draught are given as follows –

S.No.	*Natural Draught*	*Artificial Draught*
(i)	Its initial cost is high.	It is more economical.
(ii)	It cannot be controlled.	It is better in control.
(iii)	It produces comparatively less draught.	It produces more draught.
(iv)	Its rate of combustion is low.	Its rate of combustion is very high.
(v)	In this system, low grade fuel cannot be burnt properly.	Low grade fuel can be used.
(vi)	It is considerably affected by the atmospheric temperature.	It is not affected by the atmospheric temperature.
(vii)	Lower efficiency.	Higher efficiency.
(viii)	Fuel consumption is more.	Fuel consumption is less.

Q.48. Differentiate between natural draught and forced draught. **(R.G.P.V., Dec. 2011)**

Ans. Since forced draught is a type of artificial draught, therefore the basic differences between natural and forced draughts are same as those for natural and artificial draughts, which are discussed in Q.47.

Q.49. Discuss various methods of producing artificial draught.

Ans. Various methods of producing artificial draught are discussed below –

(i) Steam Jet Draught – Steam jet draught may be induced draught or forced draught depending upon where the steam jet is located. In a steam jet draught, the exhaust steam, from a non-condensing steam engine, is used for producing draught. It is mostly used in locomotive engine. In an induced steam jet draught, the steam jet issuing from the nozzle is placed in the chimney. In a forced steam jet draught, the steam jet issuing from the nozzle is placed in the ash pit under the grate of the furnace.

Induced draught produced by steam jet is shown in fig. 4.27.

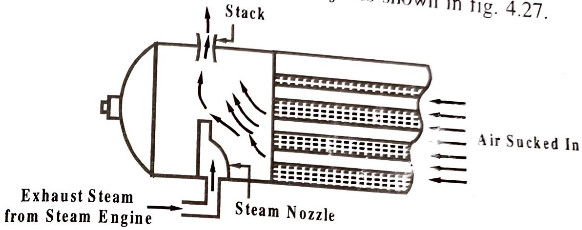


Fig. 4.27 Induced Draught Produced by Steam Jet

This system is used in a boiler for a locomotive. When the locomotive is stationary, steam from the boiler may be led to the smoke box through the nozzle to produce draught. When the locomotive is in motion, the air enters through the damper and forces its way through the grate and flues to the smoke box. But besides this, the exhaust steam from the cylinder can be led to the nozzle in the smoke box, and induced draught created.

Forced draught produced by steam jet is shown in fig. 4.28.

In forced draught, steam from the boiler is throttled by a valve to a pressure of about 1.5 to 2 bar and passed through the nozzles projecting in a diffuser pipe. The steam thus emerges out with higher velocity and drags the column of air along with it thus allowing fresh outside air to enter. Mixture of steam and air having great kinetic energy passes in the diffuser pipes. The kinetic energy

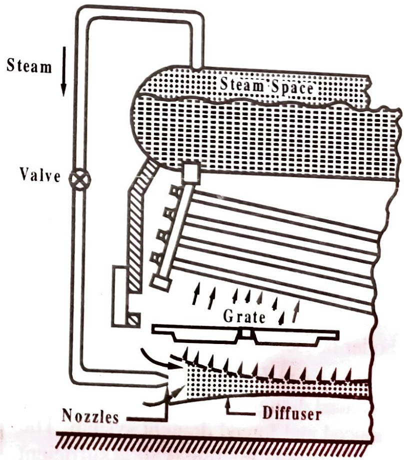


Fig. 4.28 Forced Draught Produced by Steam Jet

is converted to pressure energy and thus air is forced through the coal bed to the furnace. Normally, the natural draught or chimney draught is also provided in conjunction with steam jet draught. The steam jet draught is only an accelerating device helping to make the natural draught more effective.

(ii) Induced Draught – Schematic arrangement for the induced draught system is shown in fig. 4.29.

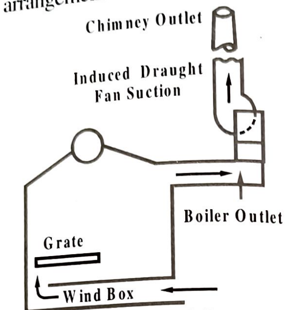


Fig. 4.29 Induced Draught

Induced draught fan is placed at the base of the chimney. It sucks in gas from the boiler side and discharges it to the stack. The suction head created by the induced fan depends upon the draught requirements. After the drop in the flue, furnace and economiser, finally a suction head should be available to draw in air through the coal bed. Since, draught is independent of the hot column of air in chimney, therefore, the gases may be let out as cold as possible after recovering as much heat as possible. In this system, function of the chimney is to dispose off the hazardous smoke and gases high up in the atmosphere. Its primary purpose it not producing draught. Therefore, height of the chimney may not be very much.

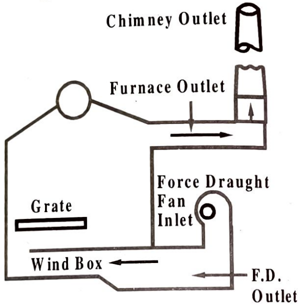


Fig. 4.30 Forced Draught

(iii) Forced Draught – In forced draught system, a fan is installed near or at the base of the boiler to force air through the coal bed and other passages through furnace, flues, economiser, air preheater etc., to the stack. Forced draught is a positive pressure draught. Schematic layout of the forced draught is shown in fig. 4.30.

The encloser for the furnace etc., has to be very tightly sealed so that gases from the furnace do not leak out in the boiler house.

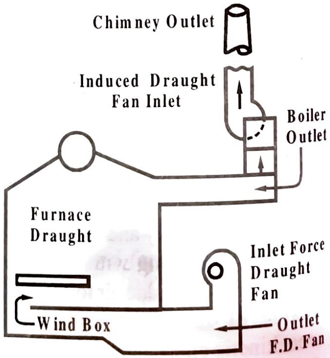


Fig. 4.31 Balanced Draught

(iv) Balanced Draught – The balanced draught is a combination of the induced and forced draught system. The forced draught fan forces air at sufficient pressure to pass through the fuel bed either direct or through the air heater

where the induced draught fan draws the flue gases through the boiler flues, economiser and preheater and, then discharges them to the top of the chimney. Schematic layout of a balanced draught is shown in fig. 4.31.

Q.50. Compare forced and induced boiler draught. **(R.G.P.V., June 2016)**

Ans. Refer Q.49.

NUMERICAL PROBLEMS

Prob.15. A chimney of 30 m height is discharging hot gases at 320°C, when outside temperature is 30°C. The air-fuel ratio is 20. Calculate –

(i) The draught produced in mm of water column

(ii) The temperature of gases for maximum discharge in a given time and what would be the draught produced corresponding.

(R.G.P.V., June 2011)

Sol. Given, H = 30 m, $T_g = 320°C = 320 + 273 = 593$ K, $T_a = 30°C = 30 + 273 = 303$ K, m = 20 kg/kg of fuel.

(i) Draught produced in mm of water

Theoretical draught in mm of water is given by,

$$h = 353H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m+1}{m}\right)\right]$$

$$= 353\times 30\left[\frac{1}{303} - \frac{1}{593}\left(\frac{20+1}{20}\right)\right]$$

$$= \mathbf{16.2\ mm\ of\ water} \qquad \textbf{Ans.}$$

(ii) For maximum discharge

Temperature of hot gases for maximum discharge is given by,

$$T'_g = 2\left(\frac{m+1}{m}\right)T_a = 2\times\left(\frac{20+1}{20}\right)\times 303 = 636.3\text{ K} = \mathbf{363.3°C}\ \textbf{Ans.}$$

Corresponding draught produced for maximum discharge,

$$h' = 353H\left[\frac{1}{T_a} - \frac{1}{2\left(\frac{m+1}{m}\right)T_a}\left(\frac{m+1}{m}\right)\right]$$

$$= \frac{353H}{2T_a} = \frac{176.5H}{T_a}$$

$$= \frac{176.5\times 30}{303} = \mathbf{17.47\ mm\ of\ water} \qquad \textbf{Ans.}$$

STEAM PROPERTIES, USE OF STEAM TABLES

Q.51. Define steam. Why is it called as a pure substance ?

Ans. Steam may be defined as the water vapours. It is used as the working medium in operation of steam turbines and steam engines. Pure steam is almost invisible. Steam as a vapour would not obey the laws of perfect gases, unless it is in a highly dried condition. Steam in such a dried condition is known as superheated steam and it can be assumed to behave like a perfect gas.

Any substance which remains chemically homogeneous and has a fixed composition which remains invariable in either phase or combination of phases, is called as a pure substance. Since steam (H_2O) has a fixed composition in all three phases, liquid, gas and solid, thus it is a pure substance.

Q.52. What is dryness fraction ? ***(R.G.P.V., Dec. 2016)***

Ans. Dryness fraction is the ratio of mass of actual dry steam to the mass of same quantity of wet steam. It is generally denoted by 'x'. Therefore,

$$x = \frac{m_g}{m_g + m_f}$$

where, m_g = Mass of actual dry steam

m_f = Mass of water in suspension.

Q.53. What is latent heat of vaporization ? ***(R.G.P.V., Dec. 2016)***

Ans. Latent means hidden, thus latent heat is the heat supplied to a substance that cannot be sensed by a thermometer. During latent heat addition, phase change occurs while temperature remains constant.

When 1 kg of water is evaporated at its boiling point without change of temperature, amount of heat absorbed is known as latent heat of vaporization. Here, heat is utilized for changing the phase of 100°C water to 100°C steam. It is denoted by h_{fg}.

Q.54. Define the following terms –

(i) Sensible heat of water
(ii) Latent heat of steam
(iii) Dryness fraction of steam
(iv) Saturation temperature of steam.

(R.G.P.V., June 2012)

Ans. (i) Sensible Heat of Water – The heat supplied to a substance, if sensed or measured by a thermometer is called sensible heat. During sensible heating only temperature rises and no phase change occurs. Sensible is equal to the enthalpy of the substance at a given pressure.

When 1 kg of water is heated at a constant pressure from the freezing point (0°C) to the temperature of formation of steam (t), then amount of heat absorbed is known as sensible heat of water. It is denoted by h_f.

Heat absorbed by water = Mass × Specific heat × Rise in temperature

Therefore,

$$\text{Sensible heat} = 1 \times 4.2 \times [(t + 273) - (0 + 273)]$$
$$= 4.2t \text{ kJ/kg}$$

[∵ Specific heat of water = 4.2 kJ/kg K]

(ii) Latent Heat of Steam – Refer Q.53.

(iii) Dryness Fraction of Steam – Refer Q.52.

(iv) Saturation Temperature – The temperature, at which water on heating vaporizes into steam, at a given pressure is termed as saturation temperature of steam. Saturation temperature of steam remains constant for a given pressure and the pressure is called saturation pressure of steam.

Q.55. Write short notes on the following –

(i) Latent heat (ii) Dryness fraction (iii) Superheat. ***(R.G.P.V., June 2010)***

Ans. (i) Latent Heat – Refer Q.53.

(ii) Dryness Fraction – Refer Q.52.

(iii) Superheat – The process of heating of dry steam is called superheating. The steam after heating is converted into superheated steam. The heat supplied during superheating is known as enthalpy of superheat.

The degree of superheat is defined as the difference beween superheated and saturated temperature of steam.

Q.56. Define specific volume of steam.

Ans. The specific volume of steam is its volume per unit mass. It is expressed in m³/kg. Specific volume decreases with increase in pressure.

Specific volume of wet steam = xv_g m³/kg

Specific volume of dry saturated steam = v_g m³/kg (∵ x = 1)

Specific volume of superheated steam

$$v_{sup} = \frac{v_g t_{sup}}{t}$$

Q.57. Explain in brief enthalpy of steam.

Ans. Enthalpy of steam is also known as total heat of steam. Enthalpy is defined as the amount of heat absorbed by water from freezing point to saturation temperature plus the heat absorbed during evaporation.

Enthalpy of steam = Latent heat + Sensible heat

(i) ***Wet Steam*** – The enthalpy of wet steam is given as

$$h = h_f + x\, h_{fg}$$

where, x = Dryness fraction of steam.

(ii) ***Dry Saturated Steam*** – In case of dry steam, $x = 1$, hence

$$h = h_g = h_f + h_{fg}$$

(iii) ***Superheated Steam*** – It we further add heat to the dry saturated steam, its temperature increases while pressure remains constant. This increase in temperature shows the superheat stage of the steam. Thus, total heat required for the steam to be superheated is,

h_{sup} = Total heat for dry steam + Heat for superheated steam

$$= h_f + h_{fg} + c_p\,(t_{sup} - t)$$

$$= h_g + c_p\,(t_{sup} - t)$$

where, t = Saturation temperature at the given constant pressure

t_{sup} = Temperature of the superheated steam

c_p = Mean specific heat at constant pressure for superheated steam.

Q.58. What is internal energy ? ***(R.G.P.V., Dec. 2014)***

Ans. Internal energy is the actual heat energy stored in steam, above the freezing point of water. The internal energy may be calculated by subtracting the external work done during evaporation from the enthalpy of steam.

Internal energy of steam

= Enthalpy – External work done during evaporation

The expressions of internal energy are given as follows –

(i) For wet steam,

$$u = h - 100\,p\,x\,v_g$$

$$= (h_f + xh_{fg}) - 100p\,x\,v_g \quad \text{kJ/kg}$$

(ii) For dry saturated steam,

$$u = (h_f + h_{fg}) - 100pv_g \quad \text{kJ/kg}$$

(iii) For superheated steam,

$$u = h_{sup} - 100\,pv_{sup}$$

$$= \{h_g + c_p(t_{sup} - t)\} - 100pv_{sup} \quad \text{kJ/kg}$$

Q.59. Explain the entropy. ***(R.G.P.V., June 2008)***

Ans. The term entropy means transformation. Entropy is a thermodynamic property of a working substance which increases with the addition of heat and decreases with removal of heat.

During evaporation of 1 kg of water at saturation temperature the heat added is equal to the latent heat of vaporization. Hence the entropy of vaporization is

$$s_{fg} = \frac{h_{fg}}{T_s}$$

Therefore, the entropy of dry and saturated steam is

$$s_s = s_g$$

$$= s_f + s_{fg}$$

Entropy of wet steam is given by

$$s = s_f + x\,s_{fg}$$

Entropy of superheated steam

$$s_{sup} = s_g + c_p \log_e \frac{T_{sup}}{T_s}$$

Q.60. Define following processes of steam –

(i) Constant pressure (ii) Constant Volume.

Ans. (i) Constant Pressure Process – In this process, the pressure of steam remains constant before and after the process. The generation of steam in a boiler is an example of constant pressure or isobaric process.

(ii) Constant Volume Process – In this process, mass or volume of the steam remains constant after the process. Since volume does not change the work done in this process is zero. The cooling or heating of the steam in a closed vessel is an example of constant volume process.

Q.61. Draw a constant pressure process on p-v, T-s and h-s diagram. Also derive expression for work done, change in internal energy and heat transferred during process.

Ans. The p-v, T-s and h-s diagrams for constant pressure process are shown in fig. 4.32 (a), (b) and (c) respectively.

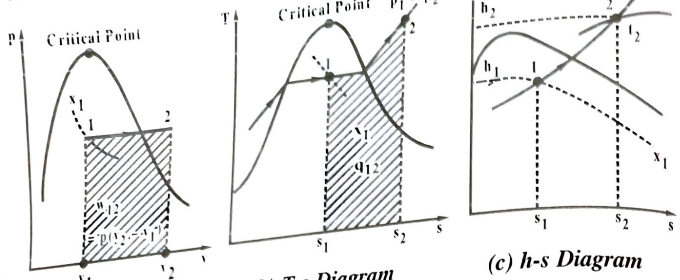
Assume the steam undergoes a constant pressure process. Let the initial condition of steam in the wet region is represented by point 1 and the final condition in the superheat region represented by point 2.

Work Done – The work done during a reversible non-flow process at constant pressure is given by

$$w_{1\text{-}2} = \int_1^2 p_1 dv = p_1\,(v_2 - v_1) \text{ kJ/kg}$$

where, $v_1 = xv_{g_1} + (1 - x)v_{f_1}$ at pressure p_1

v_2 = Volume of superheated steam corresponding to pressure $p_1 = p_2$ and temperature T_2.



(a) p-v Diagram (b) T-s Diagram (c) h-s Diagram

Fig. 4.32 Constant Pressure Process

Heat Transferred – Heat transferred during non-flow process is given by,

$$\delta q = du + pdv$$

or
$$q_{1\text{-}2} = (u_2 - u_1) + \int pdv$$
$$= (u_2 - u_1) + p_2v_2 - p_1v_1 = h_2 - h_1 \text{ kJ/kg}$$

Thus, the heat transferred at constant pressure is equal to change in enthalpy.

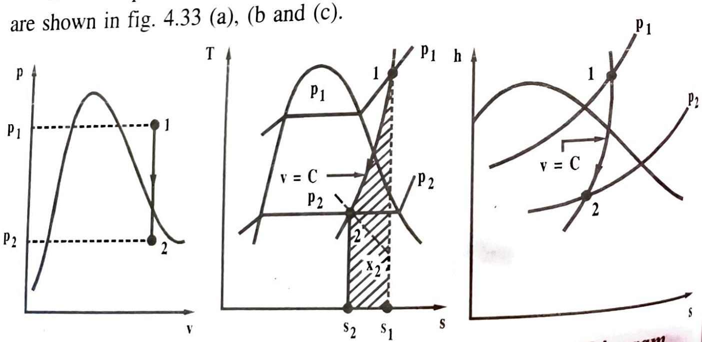
Change in Internal Energy – The change in internal energy for a constant pressure heating process is given by,

$$u_2 - u_1 = (h_2 - h_1) - (p_2v_2 - p_1v_1)$$

For constant pressure cooling process the nomenclature used for states will be interchanged.

Q.62. Derive expression for work done, change in internal energy and heat transfer during a constant volume process.

Ans. The p-v, T-s and h-s diagrams for a constant volume cooling process are shown in fig. 4.33 (a), (b and (c).



(a) p-v Diagram (b) T-s Diagram (c) h-s Diagram

Fig. 4.33 Constant Volume Process

Consider that the steam undergoes a constant volume cooling process. Let the initial condition of superheated steam be defined by pressure p_1 and superheating temperature T_1 and the final condition of steam as pressure p_2 and dryness fraction x_2, then

$$v_1 = v_{sup_1} \text{ at pressure } p_1 \text{ and temperature } T_1$$
$$v_2 = (1 - x_2)v_{f_2} + x_2v_{g_2} \text{ at pressure } p_2$$

and
$$v_1 = v_2 = v_{sup_1} = v_{f_2} + x_2v_{g_2} - x_2v_{f_2}$$

Therefore,
$$x_2 = \frac{v_{sup_1} - v_{f_2}}{v_{g_2} - v_{f_2}}$$

Work Done – Since $dv = 0$ or $\int pdv = 0$

Therefore, work done is zero in this process.

Heat Transferred – By first law of thermodynamics,

$$\delta q = du + pdv$$

or
$$q_{1\text{-}2} = (u_2 - u_1) + \int_1^2 pdv$$

But,
$$\int_1^2 pdv = 0. \text{ Therefore, } q_{1\text{-}2} = (u_2 - u_1)$$
$$= (h_2 - p_2v_2) - (h_1 - p_1v_1) \text{ kJ/kg}$$

Thus for constant volume process, the heat transferred during the process is given by the difference of internal energies at the two limits.

Change in Internal Energy – The initial internal energy of steam

$$u_1 = h_1 - 100\, p_1\, v_{sup_1} \text{ kJ/kg}$$

Final internal energy of steam

$$u_2 = h_2 - 100\, p_2\, x_2\, v_{g_2} \text{ kJ/kg}$$

$\therefore$ Change in internal energy of steam

$$du = u_2 - u_1$$

For heating process at constant volume, the nomenclature used for states will be interchanged.

Q.63. What do you mean by throttling of steam ?

Ans. When steam is forced through a restricted opening such as a narrow aperture or a slightly opened valve, it is said to be throttled. The aperture is so narrow, that due to frictional resistance between the fluid and the sides of the aperture, the velocity of outcoming fluid is almost reduced to zero. The kinetic energy is converted into heat by friction. As a result of this, if initially steam was wet, it will start drying up as it expands, and if it was dry it will become superheated. In a throttling process there is no change of potential energy, no external work is done and if pipe is well lagged there is no heat transferred.

Q.64. Explain constant enthalpy or throttling process on p-v and T-s diagram.

Ans. Consider 1 kg of wet steam throttled through a narrow aperture, between states 1 and 2.

In a throttling process –

(i) No heat is transferred, i.e., $q_{1-2} = 0$.

(ii) No work is done, i.e., $w_{1-2} = 0$.

(iii) No change in internal energy, i.e., $du = 0$.

Applying steady flow energy equation between states 1 and 2, we have

$$h_1 + \frac{V_1^2}{2} + gz_1 + q_{1-2} = h_2 + \frac{V_2^2}{2} + gz_2 + w_{1-2} \quad \text{...(i)}$$

Since datum level is same, therefore, $z_1 = z_2$. The velocities V_1 and V_2 are very small, thus $\frac{V_1^2}{2}$ and $\frac{V_2^2}{2}$ are negligible. Thus, equation (i) reduces to

$$h_1 = h_2 \quad \text{...(ii)}$$

Thus, enthalpy remains constant.

Initial enthalpy of steam before expansion

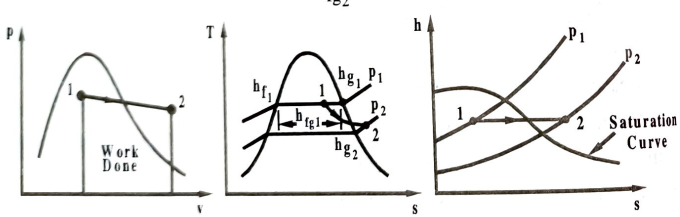
$$h_1 = h_{f_1} + x_1 h_{fg_1}$$

Final enthalpy of steam after expansion

$$h_2 = h_{f_2} + x_2 h_{fg_2}$$

or
$$h_{f_1} + x_1 h_{fg_1} = h_{f_2} + x_2 h_{fg_2}$$

$\therefore$
$$x_2 = \frac{h_{f_1} + x_1 h_{fg_1} - h_{f_2}}{h_{fg_2}}$$



(a) p-v Diagram *(b) T-s Diagram* *(c) h-s Diagram*

Fig. 4.34 Throttling or Constant Enthalpy Process

The value of x_2 gives us important informations, for example,

$x_2 < 1$ steam is wet

$x_2 = 1$ steam is dry saturated

$x_2 > 1$ steam is superheated.

The process is shown on p-v, T-s and h-s diagrams in fig. 4.34 (a), (b) and (c) respectively.

Q.65. Explain constant entropy process of vapour.

Ans. Constant entropy process is also known as reversible adiabatic process or isentropic process.

Now consider 1 kg of wet steam being heated by reversible adiabatic process.

Let, p_1 = Initial pressure of the steam in bar

v_{g_1} = Specific volume of the dry saturated steam in m^3/kg

x_1 = Initial dryness fraction of the steam

p_2, v_{g_2}, x_2 = Corresponding values for the final condition of the steam.

Initial entropy of steam before expansion

$$s_1 = s_{f_1} + \frac{x_1 h_{fg_1}}{T_1} = s_{f_1} + x_1 s_{fg_1}$$

and final entropy of the steam after expansion

$$s_2 = s_{f_2} + \frac{x_2 h_{fg_2}}{T_2} = s_{f_2} + x_2 s_{fg_2}$$

Since the entropy before expansion is equal to the entropy after expansion, therefore

$$s_{f_1} + \frac{x_1 h_{fg_1}}{T_1} = s_{f_2} + \frac{x_2 h_{fg_2}}{T_2}$$

or
$$s_{f_1} + x_1 s_{fg_1} = s_{f_2} + x_2 s_{fg_2}$$

where s_{f_1}, h_{fg_1} and T_1 represents entropy of water, latent heat or enthalpy of evaporation and temperature corresponding to pressure p_1.

s_{f_2}, h_{fg_2} and T_2 represents the corresponding values at pressure p_2. s_{fg_1} and s_{fg_2} represents entropy of evaporation.

Change in Internal Energy –

Initial internal energy of the steam,

$$u_1 = h_1 - 100\, p_1 v_1$$

where, v_1 = Initial volume of steam = $x_1 v_{g_1}$

and final internal energy of steam

$$u_2 = h_2 - 100\, p_2 v_2$$

where v_2 = Final volume of steam

$= x_2 v_{g_2}$ (For wet steam)

$= v_{g_2}$ (For dry saturated steam)

$= v_{sup}$ (For superheated steam)

$\therefore$ Change in internal energy

$$du = u_2 - u_1$$

Heat Transferred –

Since no heat is added or subtracted during an adiabatic process, therefore

$$q_{1-2} = 0$$

Work Done – According to first law of thermodynamics, the heat absorbed or heat transferred,

$$q_{1-2} = du + w_{1-2}$$

Since $q_{1-2} = 0$, during a non-flow reversible adiabatic or isentropic process, therefore work done during the process,

$$w_{1-2} = -du = u_1 - u_2$$

This shows that during a reversible adiabatic or isentropic process, work done is equal to the change in internal energy.

If the process is steady flow reversible adiabatic process or isentropic process, then according to steady flow energy equation

$$h_1 + q_{1-2} = h_2 + w_{1-2}$$

Since $q_{1-2} = 0$, therefore

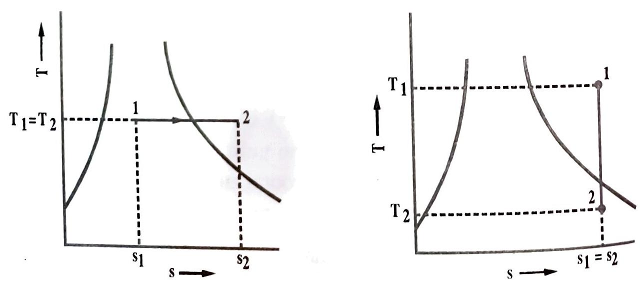
$$w_{1-2} = h_1 - h_2$$

This shows that during a steady flow reversible adiabatic process or isentropic process, work done is equal to the change in enthalpy.

Q.66. Show the various processes of steam in a T-s diagram.
(R.G.P.V., June 2014)

Ans. T-s diagrams for constant pressure process, constant volume process and constant enthalpy processs are shown in Q.61, Q.62 and Q.64, respectively, refer them.

T-s diagram for isothermal process will be a horizontal line as shown in fig. 4.35 (a) and that for an isentropic process will be a vertical line as shown in fig. 4.35 (b).



(a) Isothermal Process *(b) Isentropic Process*

Fig. 4.35

NUMERICAL PROBLEMS

Prob.16. Find enthalpy of steam at 10 bar in following conditions –
(i) Dry and saturated
(ii) Wet having dryness fraction 0.95
(iii) Superheated to a degree of superheat = 50°C.
(R.G.P.V., Dec. 2012)

Sol. Given, $p = 10$ bar, $x = 0.95$, $t_{sup} - t = 50°C$.

From steam tables at 10 bar,

$h_f = 762.6$ kJ/kg, $h_{fg} = 2013.6$ kJ/kg, $t = 179.9°C$

Now we will calculate enthalpy of steam –

(i) When steam is dry and saturated

Enthalpy of 1 kg of dry and saturated steam,

$$h = h_g = h_f + h_{fg} = 762.6 + 2013.6 = 2776.2 \text{ kJ/kg}$$ Ans.

(ii) When steam is wet

Enthalpy of 1 kg of wet steam having dryness fraction of 0.95,

$$h = h_f + xh_{fg} = 762.6 + 0.95 \times 2013.6 = \mathbf{2675.52 \text{ kJ/kg}}$$ **Ans.**

(iii) When steam is superheated

Enthalpy of 1 kg of superheated steam,

$$h_{sup} = h_g + c_p(t_{sup} - t) \quad (\text{Let } c_p = 2.1 \text{ kJ/kg K})$$
$$= 2776.2 + 2.1 \times 50$$
$$= \mathbf{2881.2 \text{ kJ/kg}}$$ **Ans.**

Prob.17. Find the enthalpy of steam at 9 bar, when it is dry saturated.
(R.G.P.V., June 2015)

Sol. Enthalpy of dry saturated steam at 9 bar, from steam tables,

$$h = h_g = \mathbf{2772.1 \text{ kJ/kg}}$$ **Ans.**

Prob.18. Using steam tables, determine the mean specific heat for superheated steam at 1 bar between temperatures of 150°C and 200°C.
(R.G.P.V., Dec. 2010)

Sol. From steam tables,

At 1 bar and 150°C, $h_{sup_1} = 2776.3$ kJ/kg

and at 1 bar and 200°C, $h_{sup_2} = 2875.4$ kJ/kg

Now mean specific heat is given by

$$c_{ps} = \frac{h_{sup_2} - h_{sup_1}}{t_2 - t_1}$$

$$= \frac{2875.4 - 2776.3}{200 - 150}$$

$$= \mathbf{1.982\ kJ/kg\ K}$$ **Ans.**

Prob.19. Calculate the internal energy of 1 kg of steam at a pressure of 10 bar, when the steam is –

(i) 0.9 dry (ii) dry saturated (iii) superheated to 250°C.

(R.G.P.V., June 2014)

Sol. Given, p = 10 bar, x = 0.9, $t_{sup} = 250$°C.

From steam tables at 10 bar.

$h_f = 762.6$ kJ/kg, $h_{fg} = 2013.6$ kJ/kg, $v_g = 0.1943$ m³/kg, t = 179.9°C.

Now we will calculate internal energy of steam, when it is –

(i) 0.9 dry

Internal enrgy of 1 kg of wet steam.

$$u = (h_f + x\ h_{fg}) - 100\ p\ x\ v_g$$
$$= (762.6 + 0.9 \times 2013.6) - 100 \times 10 \times 0.9 \times 0.1943$$
$$= 2399.97$$
$$\simeq \mathbf{2400\ kJ}$$ **Ans.**

(ii) Dry saturated

Internal energy of 1 kg of dry saturated steam,

$$u = h_f + h_{fg} - 100\ p\ v_g$$
$$= 762.6 + 2013.6 - 100 \times 10 \times 0.1943$$
$$= \mathbf{2581.9\ kJ}$$ **Ans.**

(iii) Superheated to 250°C

Internal energy of 1 kg of superheated steam,

$$u_{sup} = h_{sup} - 100\ p\ v_{sup}$$

$$= (h_f + h_{fg}) + c_p\ (t_{sup} - t) - 100\ p\ v_g \times \frac{T_{sup}}{T}$$

$$= (762.6 + 2013.6) + 2.1\ (250 - 179.9)$$

$$- 100 \times 10 \times 0.1943 \times \frac{(250 + 273)}{(179.9 + 273)}$$

(Let $c_p = 2.1$ kJ/kg K)

$$= 2776.2 + 147.21 - 224.37$$
$$= \mathbf{2699.04\ kJ}$$ **Ans.**

Prob.20. Steam at a pressure of 10 bar and a dryness of 0.9 enters a superheater and leaves at a temperature of 300°C without a drop in pressure. How much heat has been gained by the steam per kg ? Also determine the change in its internal energy. Consider specific heat at constant pressure, $c_p = 2.3$ kJ/kg K.

(R.G.P.V., Dec. 2016)

Sol. Given, $p_1 = p_2 = 10$ bar, $x_1 = 0.9$, $t_2 = 300$°C, $c_p = 2.3$ kJ/kg K.

From steam tables at 10 bar,

$h_f = 762.6$ kJ/kg, $h_{fg} = 2013.6$ kJ/kg, $h_g = 2776.2$ kJ/kg, $t_s = 179.9$°C, $v_g = 0.1943$ m³/kg.

Enthalpy of steam at inlet of superheater,

$$h_1 = h_f + x_1 h_{fg}$$
$$= 762.6 + 0.9 \times 2013.6 = 2574.84 \text{ kJ/kg}$$

Specific volume of steam at inlet of superheater,

$$v_1 = x_1 v_g$$
$$= 0.9 \times 0.1943 = 0.17487 \text{ m}^3\text{/kg}$$

Enthalpy of superheated steam at exit of superheater

$$h_2 = h_g + c_p\ (t_{sup} - t_s)$$
$$= 2776.2 + 2.3\ (300 - 179.9) \qquad (\because t_{sup} = t_2)$$
$$= 3052.43 \text{ kJ/kg}$$

and volume of superheated steam

$$v_2 = V_g \times \frac{T_{sup}}{T_s} = 0.1943 \times \frac{300 + 273}{179.9 + 273} = 0.24582 \text{ m}^3\text{/kg}$$

Heat gained by the steam

$$= h_2 - h_1$$
$$= 3052.43 - 2574.84$$
$$= \mathbf{477.59\ kJ/kg}$$ **Ans.**

Change in internal energy

$$= u_2 - u_1$$
$$= (h_2 - h_1) - (p_2v_2 - p_1v_1)$$
$$= (3052.43 - 2574.84) - [(15 \times 10^2 \times 0.24582) - (15 \times 10^2 \times 0.17487)]$$
$$= 477.59 - 106.425$$
$$= \mathbf{371.165\ kJ/kg} \qquad \textbf{Ans.}$$

Prob.21. At 1.2 MPa, 250°C steam enters into a turbine and expands to 30°C. Determine the work output of turbine for 10 kg/s of flow rate. ***(R.G.P.V., Dec. 2014)***

Sol. Given, $p_1 = 1.2$ MPa $= 12$ bar, $t_{sup_1} = 250°$C, $t_2 = 30°$C, $m = 10$ kg/s.

The expansion in turbine can assume to be reversible adiabatic, i.e. isentropic.

From tables of superheated steam at 12 bar 250°,

$$h_1 = 2935.4 \text{ kJ/kg}, \ s_1 = 6.831 \text{ kJ/kg K}$$

From temperature based steam tables at 30°C,

$p_{sat_2} = 0.04242$ bar, $h_{f_2} = 125.7$ kJ/kg, $h_{fg_2} = 2430.7$ kJ/kg, $s_{f_2} = 0.437$ kJ/kg K, $s_{fg_2} = 8.018$ kJ/kg K

Since expansion is assumed to be isentropic, therefore

$$s_1 = s_2 = s_{f_2} + x_2 s_{fg_2}$$
$$6.831 = 0.437 + x_2 \times 8.018$$

or

$$x_2 = \frac{6.831 - 0.437}{8.018} = 0.7975$$

Enthalpy of steam at the exit of turbine,

$$h_2 = h_{f_2} + x_2 h_{fg_2}$$
$$= 125.7 + 0.7975 \times 2430.7$$
$$= 2064.18 \text{ kJ/kg}$$

Thus, work output of turbine

$$= m\,(h_1 - h_2)$$
$$= 10 \times (2935.4 - 2064.18)$$
$$= 8712.2 \text{ kJ/s or } \mathbf{8712.2\ kW} \qquad \textbf{Ans.}$$

Prob.22. Steam at 18 bar and dryness friction 0.9 is heated at constant pressure until it becomes dry and saturated, find the increase in volume, heat supplied and work done per kg of steam. Further if volume of steam is kept constant, find how much heat be extracted to reduce the pressure of steam to 14 bar. ***(R.G.P.V., June 2013)***

Sol. Given, $p_1 = 18$ bar, $x_1 = 0.9$, $x_2 = 1$, $p_2 = p_1 = 18$ bar $v_2 = v_3$, $p_3 = 14$ b

(i) Constant pressure heating

At 18 bar, from steam tables,

$v_{g_1} = 0.11033$ m³/kg, $h_f = 884.5$ kJ/kg, $h_{fg_1} = 1910.3$ kJ/kg

Initial volume of steam,

$$v_1 = x_1 v_{g_1}$$
$$= 0.9 \times 0.11033 = 0.0993 \text{ m}^3/\text{kg}$$

Volume of steam after constant pressure addition,

$$v_2 = v_{g_1} = 0.11033 \text{ m}^3/\text{kg}$$

$\therefore$ Change in volume $= v_2 - v_1$

$$= 0.11033 - 0.0993$$
$$= \mathbf{0.01103\ m^3/kg} \qquad \textbf{Ans.}$$

Initial enthalpy of steam,

$$h_1 = h_{f_1} + x_1 h_{fg_1}$$
$$= 884.5 + 0.9 \times 1910.3 = 2603.77 \text{ kJ/kg}$$

Enthalpy of steam after constant pressure heat addition,

$$h_2 = h_{f_1} + h_{fg_1}$$
$$= 884.5 + 1910.3 = 2794.8 \text{ kJ/kg}$$

$\therefore$ Heat supplied $= h_2 - h_1$

$$= 2794.8 - 2603.77$$
$$= \mathbf{181.03\ kJ/kg} \qquad \textbf{Ans.}$$

Work done, $w = 100\,p_1\,(v_2 - v_1)$

$$= 100 \times 18\,(0.11033 - 0.0993)$$
$$= \mathbf{19.85\ kJ/kg} \qquad \textbf{Ans.}$$

(ii) Constant volume heat extraction

From steam tables at 14 bar,

$v_{g_3} = 0.14073$ m³/kg, $h_{f_3} = 830.1$ kJ/kg, $h_{fg_3} = 1957.7$ kJ/kg

Since volume remains constant, therefore

$$v_2 = v_3$$

$$0.11033 = x_3 v_{g_3} = x_3 \times 0.14073$$

$$\therefore \quad x_3 = 0.784$$

Internal energy of steam before constant volume process,

$$u_2 = h_2 - 100\, p_2 v_2$$

$$= 2794.8 - 100 \times 18 \times 0.11033 = 2596.2 \text{ kJ/kg}$$

and internal energy of steam after constant volume heat extraction,

$$u_3 = h_3 - 100\, p_3 v_3$$

$$= h_{f_3} + x_3 h_{fg_3} - 100\, p_3 v_2 \qquad (\because v_2 = v_3)$$

$$= 830.1 + 0.784 \times 1957.7 - 100 \times 14 \times 11033$$

$$= 2210.5 \text{ kJ/kg}$$

$\therefore$ Heat extracted by steam in constant volume process

$$= u_2 - u_3$$

$$= 2596.2 - 2210.5$$

$$= \mathbf{385.7 \text{ kJ/kg}}$$

Ans.

●●

UNIT 5

RECIPROCATING MACHINES

WORKING PRINCIPLE OF STEAM ENGINE

Q.1. State the function of steam engine. State its applications. ***(R.G.P.V., June 2016)***

Ans. A steam engine converts the heat energy of steam into mechanical energy by the action of a reciprocating piston. A steam engine receives the steam from the boiler and that steam is exhausted to either atmosphere or into the condenser.

The steam engines find their applications in locomotives, ships and in other areas, where small power and low speeds are required. Its main advantage is that engine speed can be reversed. However, it has a low thermal efficiency.

Q.2. What is a steam engine ? Give its classification. (R.G.P.V., Dec. 2011)

Ans. For steam engine, refer Q.1.

Classification – Steam engines may be classified by the following ways –

(i) According to number of working strokes
   (a) Single acting steam engine (b) Double acting steam engine.
(ii) According to the position of the cylinder
   (a) Horizontal steam engine (b) Vertical steam engine.
(iii) According to the speed of the crankshaft
   (a) Slow speed steam engine (b) Medium speed steam engine
   (c) High speed steam engine.
(iv) According to the type of exhaust
   (a) Condensing steam engine (b) Non-condensing steam engine.
(v) According to the expansion of the steam in the engine cylinder
   (a) Simple steam engine (b) Compound steam engine.

Q.3. Explain working principle of a steam engine. (R.G.P.V., Feb. 2010)

Or

Explain the working of a double acting steam engine with the help of a neat diagram. ***(R.G.P.V., June 2012)***

Ans. In the piston cylinder arrangement of steam engine, there are two inlet ports 'A' and 'B' as shown in fig. 5.1. The superheated steam at a high

pressure about 20 atm from the boiler is entered into the steam chest. If piston is at inner dead position, steam enters into the cylinder through the port 'A' and it pushes the piston to the right side. At this stage, the slide valve covers the exhaust port and the other steam port 'B'. Since the pressure of steam is greater on the left side than the right side, the piston moves to the right.

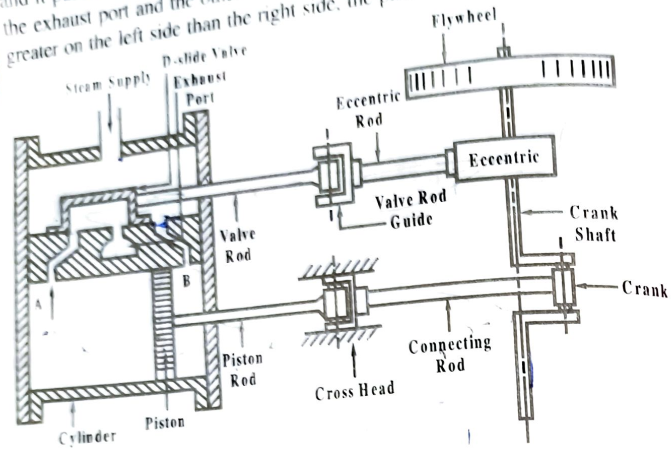


Fig. 5.1 Single Cylinder Double Acting Horizontal Reciprocating Steam Engine

The steam port 'B' gets open, when the piston reaches near the end of the cylinder. The steam port 'A' and exhaust port is now closed. Now, steam enters into the cylinder through the right side port 'B' and it pushes the piston to the left side and at the same time the exhaust steam goes out through the exhaust pipe, and thus completes the cycle of operation. The same process is repeated in other cycles of operation, and as such the engine works.

Q.4. Name the different parts of a steam engine.(R.G.P.V., Dec. 2016)

Or

Give list of parts of double acting steam engine.(R.G.P.V., June 2015)

Ans. Different parts of a steam engine are listed below –

(i) Piston	(ii) Connecting rod
(iii) Crosshead	(iv) Stuffing box
(v) Flywheel	(vi) Governor
(vii) Eccentric	(viii) D-slide valve
(ix) Main bearing	(x) Frame
(xi) Cylinder	(xii) Steam chest
(xiii) Inlet and exhaust ports	(xiv) Eccentric rod and valve rod.

Q.5. What is the function of connecting rod in heat engines ?

(R.G.P.V., June 2015)

Ans. Connecting rod is made of forged steel. Its one end is connected to the crosshead by the gudgeon pin and the other end is connected to the crank. Its function is to convert reciprocating motion of the piston into rotary motion of the crank.

Q.6. Discuss the working principle and functions of each part of steam engine.

(R.G.P.V., June 2011)

Ans. **Working Principle** – Refer Q.3.

Functions of Parts – A steam engine consists of the following parts –

(i) Piston – Piston is a cast iron cylindrical disc moving to and fro. It moves in the cylinder by the action of steam pressure. It transmits force to the crosshead through the piston rod. Cast iron piston rings make the piston steam tight in the cylinder and thereby prevent the leakage of steam past the piston.

(ii) Connecting Rod – Refer Q.5.

(iii) Crosshead – It is a link between the piston rod and connecting rod. Its function is to guide the motion of the piston rod and to prevent it from bending.

(iv) Stuffing Box – It is fitted on the crank end side of the cylinder. The main function of the stuffing box is to prevent the leakage of the steam from the cylinder to atmosphere.

(v) Flywheel – Flywheel is mounted on the crankshaft. Its function is to prevent the fluctuation of engine. It stores the energy when excess energy is transmitted to the crank and gives it back to the engine when the power developed by the engine at the crankshaft is minimum.

(vi) Eccentric – It is fitted to the crankshaft. Its function is to provide reciprocating motion to the slide valve.

(vii) D-slide Valve – The function of a D-slide valve is to connect the cylinder to the steam chest and to exhaust steam from the cylinder at proper moment.

(viii) Engine Governor – It is a device used for keeping the speed of the engine, more or less, uniform at all loads. It controls either the quantity or pressure of the steam supplied to the engine according to the load on the engine.

(ix) Main Bearing – These are fitted on the engine frame. The function of main bearings is to support the engine crankshaft.

(x) Frame – Frame is a heavy cast iron part, which supports all the stationary as well as moving parts. It generally, rests on engine foundations.

(xi) Cylinder – It is a cast iron cylindrical hollow vessel. Both ends of the cylinder are closed and made steam tight. In small steam engines, the cylinder is made an integral part of the engine.

(xii) Steam Chest – It is casted as an integral part of the cylinder. It supplies steam to the cylinder with the movement of D-slide valve.

(xiii) Inlet and Exhaust Ports – Inlet and exhaust ports are the holes provided in the body of the cylinder for the movement of steam. The steam is admitted from the steam chest alternately to either sides of the cylinder through the inlet ports. The steam after doing its work in the cylinder, is exhausted through the exhaust port.

(xiv) Eccentric Rod and Valve Rod – Eccentric rod is made of forged steel, whose one end is attached to the eccentric and other to the valve rod. Its function is to convert rotary motion of the crankshaft into to and fro motion of the valve rod. The valve rod connects the eccentric and the D-slide valve. Its function is to provide simple harmonic motion to the D-slide valve.

Q.7. Draw a neat sketch of steam engine. State the function of any five important components. **(R.G.P.V., Dec. 2010)**

Ans. A steam engine is shown in fig. 5.2.

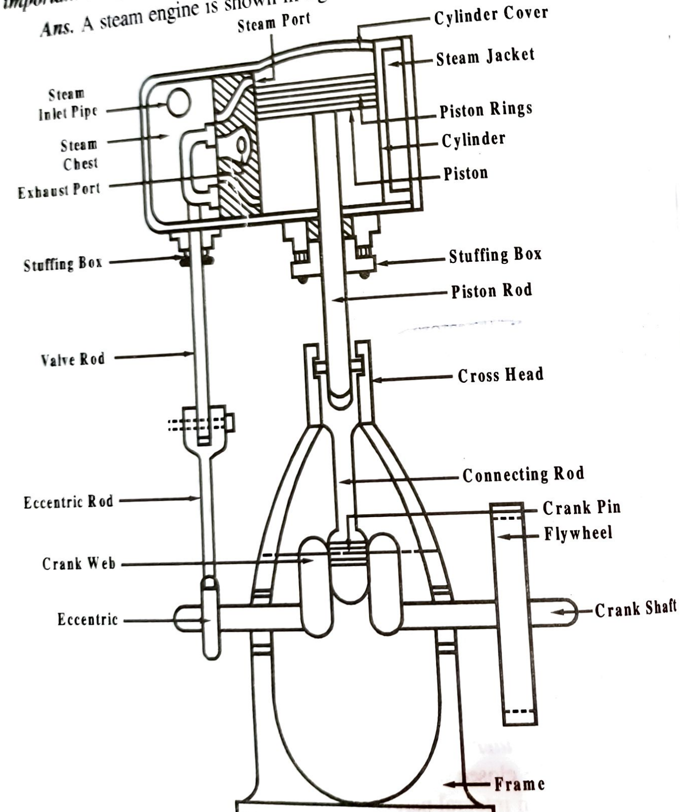


Fig. 5.2 Steam Engine

For function of five components of steam engine, refer Q.6.

Q.8. Define the term diagram factor, as applied to a steam engine. Also define the term indicator diagram and explain how it is obtained? **(R.G.P.V., Dec. 2013)**

Ans. **Indicator Diagram** – The indicator diagram is the representation of the variation of pressure and volume of the steam inside the cylinder on p-v diagram for one complete cycle of operations.

To draw the indicator diagram an instrument known as indicator is fitted on the engine cylinder. This moves according to the pressure-volume variation in the cylinder, and thus produces the indicator diagram.

Diagram Factor – The diagram factor is the ratio of the area of actual indicator diagram to the area of theoretical indicator diagram. It is usually denoted by K.

Mathematically,

$$K = \frac{\text{Area of actual indicator diagram}}{\text{Area of theoretical indicator diagram}}$$

or

$$K = \frac{\text{Actual work done per stroke}}{\text{Theoretical work done per stroke}}$$

or

$$K = \frac{\text{Actual mean effective pressure} \times \text{Swept volume}}{\text{Theoretical m.e.p.} \times \text{Swept volume}}$$

or

$$K = \frac{\text{Actual mean effective pressure}}{\text{Theoretical mean effective pressure}}$$

Since, area of actual indicator diagram is less than the area of theoretical indicator diagram, therefore the value of diagram factor is always less than unity. Its value lies between 0.65 and 0.9.

Q.9. How is the mean effective pressure for reciprocating engine defined? **(R.G.P.V., Dec. 2015)**

Ans. Mean effective pressure, p_m, is defined as a hypothetical pressure which is acting on the piston throughout the power stroke. It can be taken as the average height of the p-v diagram of the cycle or indicator diagram of any actual engine.

Q.10. Define following terms –

(i) Cut-off volume ***(ii) Release and back pressure***

(iii) Compression ratio.

Ans. *(i) Cut-off Volume* – The point at which the supply of steam in the cylinder is stopped is known as the point of cut-off and the volume of steam in the cylinder at that point is known as cut-off volume.

(ii) Release and Back Pressure – The pressure at which exhaust port is opened and the steam in the cylinder is released into the exhaust pipe is known as release pressure. Due to opening of exhaust port, steam pressure

suddenly drops to the condenser pressure p_b which is known as back pressure on the piston.

(iii) Compression Ratio – It is the ratio of total volume to clearance volume.

Q.11. What is clearance volume ? **(R.G.P.V., Dec. 2016)**

Ans. The space between the cylinder cover and the piston, when the piston is at inner dead centre position is called clearance. The clearance prevents the piston from striking the cylinder head and provides the cushioning effect to the piston at the end of exhaust stroke and at the beginning of power stroke. The volume of this space is called clearance volume (v_c). It is usually given as a percentage of stroke volume.

Q.12. Define the following terms as applied to a steam engine –
(i) Clearance (ii) Swept volume (iii) Mean piston speed
(iv) Dead centres (v) Crank throw (vi) Piston stroke
(vii) Cylinder bore. **(R.G.P.V., Dec. 2013)**

Ans. (i) Clearance – Refer Q.11.

(ii) Swept Volume – Stroke volume is the volume swept by the piston during its travel between two limiting positions (i.e., dead centres). It is also known as piston displacement or swept volume and denoted by v_s.

Mathematically,

$$v_s = \frac{\pi}{4} \times D^2 \times L$$

where, D = Bore diameter of the cylinder
L = Length of stroke.

(iii) Mean or Average Piston Speed – The distance travelled by the piston per unit time is known as average piston speed.

Average piston speed = LN m/min, for single acting steam engine
= 2 LN m/min, for double acting steam engine.

where, N = Engine speed in r.p.m.
L = Length of stroke in metres.

(iv) Dead Centres – The position of piston at the end of the stroke, when piston rod, connecting rod and crank are in the same straight line is called dead centre. There are two dead centres –

(a) Inner dead centre (I.D.C.) (b) Outer dead centre (O.D.C.).

In horizontal engine, the inner most position of the piston is known as I.D.C., whereas the outer most position of the piston is called O.D.C.

(v) Crank Throw – The distance from the centre of the crank pin to the centre of the crankshaft is known as the radius of the crank or crank throw. This distance is half of the piston stroke.

(vi) Piston Stroke – The distance through which a working piston moves between two successive reversals of its direction of motion, i.e. the distance travelled by the piston from the cover end of the cylinder to the crank end, is known as piston stroke. It is denoted by L.

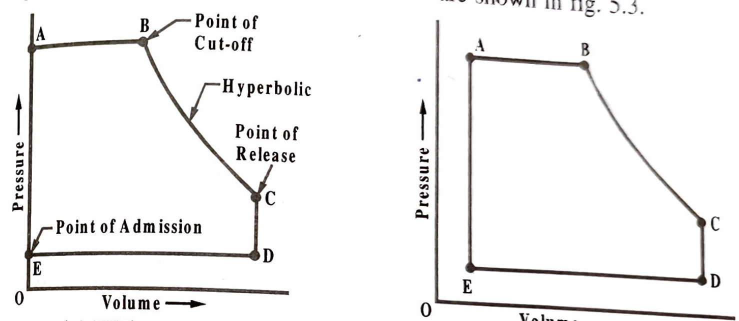
(vii) Cylinder Bore – The inside diameter of the cylinder is known as cylinder bore. It is denoted by D.

Q.13. Explain with suitable p-v diagram the working principle of a steam engine. **(R.G.P.V., Dec. 2017)**

Or

Draw the hypothetical indicator diagram of a steam engine. **(R.G.P.V., Dec. 2014)**

Ans. The theoretical or hypothetical indicator (p-v) diagram of a steam engine without clearance and with clearance are shown in fig. 5.3.



(a) Without Clearance ***(b) With Clearance***

Fig. 5.3

Various processes which occur in the steam engine are discussed below –

(i) Admission – At point A, the steam starts to admitted into the cylinder through the inlet port, at constant pressure. The point B, where supply of steam is cut-off, is known as point of cut-off.

(ii) Expansion – In the cylinder, steam expands hyperbolically from point B to C, with the movement of the piston towards bottom dead centre. During this process, pressure falls considerably.

(iii) Release – At point C, known as release point, the exhaust port opens and steam is released from the cylinder to the exhaust pipe. During the process C-D, pressure falls suddenly while volume remains constant.

(iv) Exhaust – The steam is exhausted at the constant pressure during the process D-E. The steam pressure at point D is called back pressure.

(v) Process E-A – At point E, the inlet port is opened and some steam rushes into the cylinder, which increases the steam pressure without change in volume. This process continues till the original position is restored.

Q.14. What is steam engine ? Explain its actual working with the help of actual indicator diagram. ***(R.G.P.V., June 2013)***

Ans. **Steam Engine –** Refer Q.1.

Working – The actual indicator diagram of a steam engine is shown in fig. 5.4.

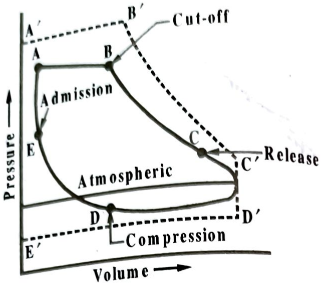


Fig. 5.4 Actual Indicator Diagram

Various processes which occur in a steam engine are discussed below –

(i) Admission – The inlet valve opens at A and the steam from the steam chest is admitted into the cylinder. This causes the steam pressure in the cylinder to rise suddenly to the boiler pressure. Thus the steam is admitted into the cylinder at the boiler pressure. The actual boiler pressure is less than that in hypothetical indicator diagram (shown by dashed lines) A', because of the friction. Further, the pressure during admission (shown by AB) does not remain constant, and drops gradually, due to the condensation of steam in the boiler.

(ii) Cut-off – Cut-off of steam is shown by point B, as cut-off does not take place instantaneously, there is the rounding-off of the diagram at B.

(iii) Expansion – The actual expansion of steam does not follow a hyperbolic curve as assumed in hypothetical indicator diagram. This is due to the varying interchange of heat through the cylinder wall.

(iv) Release – At C, exhaust valve opens and the steam in the cylinder is released into the exhaust pipe. However, opening of exhaust valve is not instantaneous, and the rounding-off of the diagram takes place at C.

(v) Exhaust – The DE represents the exhausting of the steam. The actual exhaust pressure is more than that assumed in hypothetical indicator diagram. This is required to overcome the frictional resistances.

Q.15. Explain the following related to steam engine –
(i) Hypothetical indicator diagram
(ii) Actual indicator diagram. ***(R.G.P.V., June 2016)***

Ans. Refer Q.13 and Q.14.

Q.16. Why does actual indicator diagram differ from theoretical diagram ? Explain them. ***(R.G.P.V., June 2010)***

Ans. The deviation of the actual indicator diagram shown in fig. 5.4, to that of theoretical are due to following reasons –

(i) A clearance between piston and cylinder head has to be provided for, due to mechanical reasons. This reduces the stroke length of the diagram.

(ii) There is a big drop in steam pressure between the boiler and the engine cylinder. This is due to condensation caused by loss of heat in the pipes, throttling of steam in the valves and friction in pipes.

(iii) Steam pressure does not remain constant but drops gradually till the point of cut-off is reached. This is mainly due to the condensing of the steam in the cylinder because the cylinder walls are at relatively low temperature than the steam.

(iv) Cut-off of steam does not take place instantaneously. This results in the rounding-off of the diagram at B.

(v) The expansion curve is not truly hyperbolic but follows the curve BC. This is due to the varying interchange of heat through the cylinder wall.

(vi) The steam port opens to the exhaust before at C in order to allow the pressure to drop before the piston begins its return stroke.

(vii) The opening of the exhaust valve is not instantaneous. This results in the rounding of the diagram at the point of release.

(viii) The exhaust pressure is above the condenser pressure as the steam is being forced out of the cylinder overcoming resistance.

Q.17. Explain thermal efficiency for steam engines in brief.

Ans. The thermal efficiency is defined as the ratio of the heat converted into useful work, to the heat supplied.

The heat supplied per kg of steam to the engine is given by the difference between the enthalpy of steam at admission pressure (h_1) and enthalpy of water at back pressure or engine exhaust (h_{fb}), i.e.

$$\text{Heat supplied} = (h_1 - h_{fb}) \text{ kJ/kg}$$

If m_s be the mass of steam used in kg/min, then total heat supplied

$$= \frac{m_s(h_1 - h_{fb})}{60} \text{ kJ sec}$$

The useful work obtained may be worked out either from indicated power or brake power. Accordingly, the thermal efficiency may be indicated thermal efficiency or brake thermal efficiency.

(i) Indicated Thermal Efficiency – It is defined as the ratio of heat equivalent of indicated power to the energy in the steam supplied per minute.

$$\therefore \quad \text{Indicated thermal efficiency} = \frac{\text{I.P.} \times 60}{m_s(h_1 - h_{fb})}$$

(ii) Brake Thermal Efficiency – It is defined as the ratio of heat equivalent of brake power to the energy in the steam supplied per minute.

$$\text{Brake thermal efficiency} = \frac{\text{B.P.} \times 60}{m_s(h_1 - h_{fb})}$$

Q.18. Define the following with relation to steam engine –
(i) Mechanical efficiency (ii) Relative efficiency
(iii) Overall efficiency.

Ans. (i) ***Mechanical Efficiency*** – Mechanical efficiency is the ratio of brake power to indicated power.

$$\text{Mechanical efficiency, } \eta_m = \frac{\text{Brake power (B.P.)}}{\text{Indicated power (I.P.)}}$$

or

$$\eta_m = \frac{\text{I.P.} - \text{F.P.}}{\text{I.P.}} \qquad [\because \text{B.P.} = \text{I.P.} - \text{F.P.}]$$

(ii) ***Relative Efficiency*** – It is also known as efficiency ratio. Relative efficiency is defined as the ratio of thermal efficiency to the Rankine efficiency.

$$\text{Relative efficiency} = \frac{\text{Thermal efficiency}}{\text{Rankine efficiency}}$$

(iii) ***Overall Efficiency*** – It is defined as the ratio of the work obtained at the crankshaft in a given time to the energy supplied by fuel during the same time.

$$\text{Overall efficiency, } \eta_o = \frac{\text{B.P} \times 60 \times 60}{m_f \times \text{C.V.}} = \frac{\text{B.P.} \times 3600}{m_f \times \text{C.V.}}$$

where, m_f = Mass of fuel burnt in kg/hr

C.V. = Calorific value of fuel in kJ/kg of fuel.

Q.19. Derive expressions to determine hypothetical mean effective pressure of a steam engine in the following cases –
(i) Without clearance (ii) With clearance.

Ans. (i) ***Without Clearance*** – The hypothetical mean effective pressure without clearance is calculated as follows –

Let, p_1 = Admission pressure of steam or boiler pressure

p_b = Back pressure or condenser pressure

v_2 = Volume of steam at point 2 (i.e., cut-off point)

v_3 = Total volume of steam in the cylinder.

Hypothetical work done per cycle

= Area of diagram 123451

= Area 12QP + area 23RQ – area 54RP

$$= p_1v_2 + 2.3p_1v_2\log_{10}\left(\frac{v_3}{v_2}\right) - p_bv_3$$

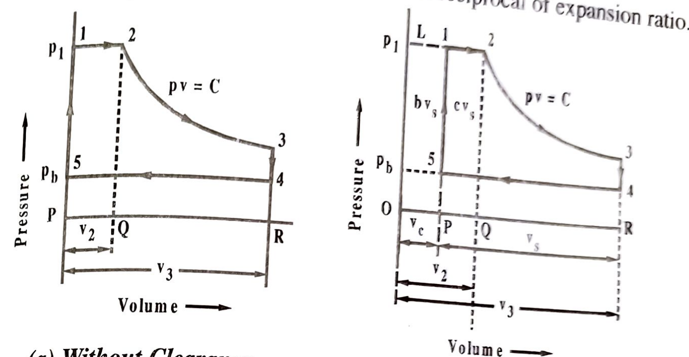
Hypothetical mean effective pressure,

$$p_m = \frac{\text{Work done per cycle}}{\text{Stroke volume}}$$

$$= \frac{p_1v_2 + 2.3p_1v_2\log_{10}\left(\frac{v_3}{v_2}\right) - p_bv_3}{v_3} = \frac{p_1}{r}(1 + 2.3\log_{10} r) - p_b$$

where, $r = \frac{v_3}{v_2}$ = Expansion ratio.

The ratio $\frac{v_2}{v_3}$ is known as cut-off ratio. It is reciprocal of expansion ratio.



(a) Without Clearance *(b) With Clearance*

Fig. 5.5 Theoretical Indicator Diagram

(ii) ***With Clearance*** – The hypothetical indicator diagram with clearance is shown in fig. 5.5 (b).

Let, p_1 = Admission pressure of steam

p_b = Back pressure

v_2 = Volume of steam at point 2 (i.e., cut-off point)

v_3 = Total volume of the steam in cylinder

v_c = Clearance volume of the cylinder

v_s = Swept volume or stroke volume or piston displacement volume

b = Ratio of clearance volume to stroke volume

$$= \frac{v_c}{v_s}$$

c = Ratio of volume between the points of admission and cut-off of steam to the stroke volume

$$= \frac{v_2 - v_c}{v_s}$$

Hypothetical work done per cycle

= Area of diagram 123451

= Area 12QP + area 23RQ – area 45PR

$= p_1(v_2 - v_c) + 2.3p_1v_2 \log_{10}(v_3/v_2) - p_bv_s$

Hypothetical mean effective pressure,

$$p_m = \frac{\text{Work done per cycle}}{\text{Swept volume}}$$

$$p_m = \frac{p_1(v_2 - v_c) + 2.3 p_1 v_2 \log_{10}(v_3/v_2) - p_b v_s}{v_s}$$

or
$$p_m = p_1\left(\frac{v_2 - v_c}{v_s}\right) + 2.3\frac{p_1 v_2}{v_s}\log_{10}\left(\frac{v_3}{v_2}\right) - p_b \qquad \text{...(i)}$$

Substituting $b = \frac{v_c}{v_s}$ and $c = \frac{v_2 - v_c}{v_s}$ in equation (i), we get

$$p_m = p_1 c + 2.3\, p_1\left(\frac{bv_s + cv_s}{v_s}\right)\log_{10}\left(\frac{v_c + v_s}{bv_s + cv_s}\right) - p_b$$

or
$$p_m = p_1 c + 2.3\, p_1(b+c)\log_{10}\left(\frac{bv_s + v_s}{bv_s + cv_s}\right) - p_b \qquad (\because v_c = bv_s)$$

or
$$p_m = p_1 c + 2.3 p_1\,(b+c)\log_{10}\left(\frac{b+1}{b+c}\right) - p_b$$

where, $\frac{b+1}{b+c} = \frac{v_3}{v_2} = r = \text{Expansion ratio}$ and $\frac{1}{r}$ = cut-off ratio.

$$\text{Since, cut-off ratio} = \frac{\text{Volume of steam in the cylinder at the point of cut-off}}{\text{Volume of steam in the cylinder at the end of stroke}}$$

$$= \frac{v_2}{v_3} = \frac{bv_s + cv_s}{v_c + v_s} = \frac{b+c}{b+1}.$$

Numerical Problems

Prob.1. Dry saturated steam at 10 bar is admitted into the cylinder of a double acting, single cylinder steam engine. The cylinder diameter is 275 mm and stroke 650 mm. Cut-off occurs at 50% of the stroke length and pressure is 1.5 bar. Assuming a diagram factor of 0.75, find the indicated power of the engine, if it runs at 380 r.p.m. **(R.G.P.V., Dec. 2011)**

Sol. Given, p_1 = 10 bar, D = 275 mm = 0.275 m, L = 650 mm = 0.65 m, cut-off = 50%, p_b = 1.5 bar, K = 0.75, N = 380 r.p.m.

Since cut-off occurs at 50%, therefore expansion ratio,

$$r = \frac{1}{0.5} = 2$$

Actual mean effective pressure,

$$p_a = K\left[\frac{p_1}{r}(1 + 2.3\log_{10} r) - p_b\right]$$

$$= 0.75\left[\frac{10}{2}(1 + 2.3\log_{10} 2) - 1.5\right] = 5.22 \text{ bar}$$

Indicated power,

$$\text{I.P.} = \frac{2 \times 100 p_a LAN}{60}$$

$$= \frac{2 \times 100 \times 5.22 \times 0.65 \times \frac{\pi}{4} \times (0.275)^2 \times 380}{60}$$

$$= \mathbf{255.3\ kW}$$

Ans.

Prob.2. A double acting steam engine has a single cylinder of diameter 700 mm by 900 mm and develops 450 kW indicated power at 90 r.p.m. pressure at the point of cut-off is 12 bar, back pressure is 1.3 bar and diagram factor is 0.76, calculate the expansion ratio. **(R.G.P.V., Dec. 2016)**

Sol. Given, D = 700 mm = 0.7 m, L = 900 mm = 0.9 m, I.P. = 450 kW, N = 90 r.p.m., p_1 = 12 bar, p_b = 1.3 bar, K = 0.76.

For double acting steam engine, indicated power is given by

$$\text{I.P.} = \frac{2 \times 100\, p_a LAN}{60}$$

$$450 = \frac{2 \times 100 \times p_a \times 0.9 \times \frac{\pi}{4} \times (0.7)^2 \times 90}{60}$$

$$450 = 103.91\, p_a$$

$\therefore$ $$p_a = 4.33 \text{ bar}$$

But $$p_a = p_m \times k$$

$$4.33 = p_m \times 0.76$$

$\therefore$ $$p_m = \frac{4.33}{0.76} = 5.7 \text{ bar}$$

The mean effective pressure is given by

$$p_m = \frac{p_1}{r}(1 + 2.3\log_{10} r) - p_b$$

$$5.7 = \frac{12}{r}(1 + 2.3\log_{10} r) - 1.3$$

or
$$\frac{(5.7 + 1.3)r}{12} = 1 + 2.3\log_{10} r$$

or
$$\frac{7r}{12} - 1 = 2.3\log_{10} r$$

$$\frac{7r}{12} - 1 = \log_e r$$

or $$r = e^{\left(\frac{7r}{12} - 1\right)}$$

or On solving above equation, we get

Expansion ratio, $r = \mathbf{4.157}$ **Ans.**

Prob.3. Steam is admitted to an engine for 30% of the stroke with a pressure of 7 bar. The law of expansion followed is $pv^{1.15} = c$. Compression commences at 60% of return stroke and follows the law $pv^{1.3} = c$, the clearance volume is 20% of the displacement volume and the back pressure is 648 mm of Hg vacuum, when barometer reads 760 mm of Hg. Estimate the mean effective pressure of a double acting engine with cylinder diameter 30 cm, stroke 45 cm and speed 200 r.p.m.

Sol. Indicator diagram for the problem is shown in fig. 5.6.

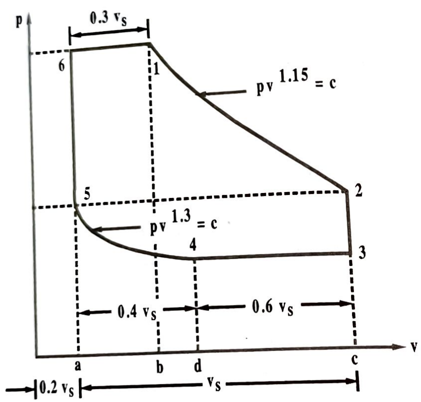


Fig. 5.6

$\because$ 1 bar = 750.062 mm Hg

$\therefore$ Back pressure, p_b = 648 mm of Hg vacuum

$$= \frac{760 - 648}{750.062} \text{ bar} = 0.1493 \text{ bar}$$

Expansion follows the law $pv^{1.15} = c$, thus,

$$p_1 v_1^{1.15} = p_2 v_2^{1.15}$$

or $$p_2 = p_1\left(\frac{v_1}{v_2}\right)^{1.15} = 7 \times \left(\frac{0.5v_s}{1.2v_s}\right)^{1.15} = 2.558 \text{ bar}$$

Compression follows the law $pv^{1.3}$, thus,

$$p_4 v_4^{1.3} = p_5 v_5^{1.3}$$

or $$p_5 = p_4\left(\frac{v_4}{v_5}\right)^{1.3}$$

$$= 0.1493\left(\frac{0.4v_s + 0.2v_s}{0.2v_s}\right)^{1.3}$$

$$= 0.6227 \text{ bar} \qquad (\because p_4 = p_b)$$

Mean effective pressure

$$p_m = \frac{\text{Area of the indicator diagram}}{\text{Stroke volume}}$$

$$= \frac{\text{Area 61ba + Area 12cb − Area 43cd − Area 54da}}{v_s}$$

$$= \left[\left\{(7 \times 0.3v_s) + \left(\frac{7 \times 0.5v_s - 2.558 \times 1.2v_s}{1.15 - 1}\right)\right\} - \left\{(0.1493 \times 0.6v_s) + \left(\frac{0.6227 \times 0.2v_s - 0.1493 \times 0.6v_s}{1.3 - 1}\right)\right\}\right] \div v_s$$

$= \mathbf{4.7632\ bar}$ **Ans.**

Prob.4. The following data were obtained during the trial of a single cylinder, double acting steam engine –

Speed = 104.5 r.p.m., cylinder diameter = 220 mm, piston stroke = 300 mm, m.e.p. (each end) = 120 kPa, effective brake diameter = 1.2 m, dead load on the brake = 726 N, spring balance reading = 176 N, pressure of steam supplied = 700 kPa, steam used/hr = 57 kg, condensate temperature = 50°C. Steam supplied was dry and saturated. Calculate the mechanical efficiency and indicated and brake thermal efficiencies of the engine.

(R.G.P.V., Jan./Feb. 2006)

Sol. Given, N = 104.5 r.p.m., D = 220 mm = 0.22 m, L = 300 mm = 0.3 m, p_m = 120 kPa = 120 × 10^3 Pa, D_b = 1.2 m, W = 726 N, S = 176 N, p_1 = 700 kPa = 700 × 10^3 Pa, m_s = 57 kg/hr = 0.01583 kg/s, t_s = 50°C.

For a double acting steam engine,

$$\text{Indicated power, I.P.} = \frac{2p_m LAN}{60}$$

$$= \frac{2 \times 120 \times 10^3 \times 0.3 \times \frac{\pi}{4} \times (0.22)^2 \times 104.5}{60}$$

$$= 4767 \text{ W} = 4.767 \text{ kW}$$

Brake power, $B.P. = \frac{(W-S)\pi D_b N}{60} = \frac{(726-176)\pi \times 1.2 \times 104.5}{60}$

$= 3611.3 \text{ W} = 3.611 \text{ kW}$

$\therefore$ Mechanical efficiency,

$$\eta_m = \frac{B.P.}{I.P.} = \frac{3.611}{4.767} = 0.7575 \text{ or } \mathbf{75.75\%}$$ **Ans.**

At 700 kPa (i.e. 7 bar) from steam tables, enthalpy of dry saturated steam,

$$h_{g_1} = 2762 \text{ kJ/kg}$$

Heat remaining in condensate,

$$h_2 = 4.187 \times (t_s - 0)$$
$$= 4.187 \times (50 - 0) = 209.3 \text{ kJ/kg}$$

$\therefore$ Heat energy supplied in steam,

$$h_s = m_s (h_{g_1} - h_2)$$
$$= 0.01583 \times (2762 - 209.3) = 40.41 \text{ kJ/s}$$

Now indicated thermal efficiency of the engine,

$$\eta_i = \frac{\text{Heat equivalent of I.P. in kJ/s}}{\text{Heat supplied in steam in kJ/s}} = \frac{4.767}{40.41} = 0.118 \text{ or } \mathbf{11.8\%}$$ **Ans.**

and brake thermal efficiency of the engine,

$$\eta_b = \frac{\text{Heat equivalent of B.P. in kJ/s}}{\text{Heat supplied in steam in kJ/s}} = \frac{3.611}{40.41} = 0.0894 \text{ or } \mathbf{8.94\%}$$ **Ans.**

CARNOT, OTTO, DIESEL AND DUAL CYCLES, p-v & T-s DIAGRAMS AND THEIR EFFICIENCY

Q.20. What is Carnot cycle and its importance ? (R.G.P.V., June 2014)

Ans. The Carnot cycle was introduced by a French military engineer Nicolas Sadi Carnot. In this cycle, the working substance, after passing through a sequence of events, is brought back to its initial state. The Carnot cycle has air as its working substance enclosed in a cylinder, in which a frictionless piston moves. The walls of the piston and cylinder are perfectly insulated. However, the bottom of the cylinder can be covered by an insulating cap.

Although the Carnot cycle is an ideal cycle and not possible in actual practice, it helps the designer to arrive at maximum possible efficiency that can be obtained in any heat engine under given conditions. Also on the basis of the Carnot cycle Clausius and Kelvin were able to define the second law of thermodynamics.

Q.21. Draw the p-v diagram of Carnot cycle and express its efficiency.
(R.G.P.V., Dec. 2014)

Ans. In a Carnot cycle, the working substance is subjected to a cyclic operation consisting of two isothermal and two reversible adiabatic or isentropic operations. The p-v diagram of Carnot cycle is shown in fig. 5.7.

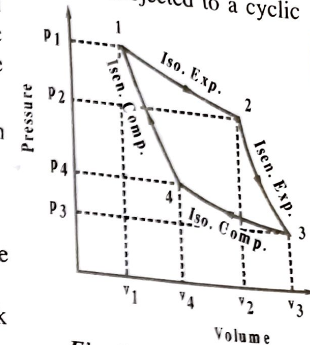


Fig. 5.7 p-v Diagram

The efficiency of a Carnot cycle is given as,

$$\eta = \frac{T_1 - T_2}{T_1}$$

where, T_1 = Temperature of the heat source (or hot body)

T_2 = Temperature of the heat sink (or cold body).

Q.22. Write short note on – Carnot cycle. **(R.G.P.V., Dec. 2017)**

Ans. Refer Q.20 and Q.21.

Q.23. Explain carnot cycle and find expression for ideal efficiency of carnot engine. **(R.G.P.V., June 2015)**

Or

Explain Carnot cycle and find expression for efficiency.
(R.G.P.V., Dec. 2012)

Ans. The Carnot cycle on p-v diagram is shown in fig. 5.7. (Q.21) and on T-s diagram is shown in fig. 5.8.

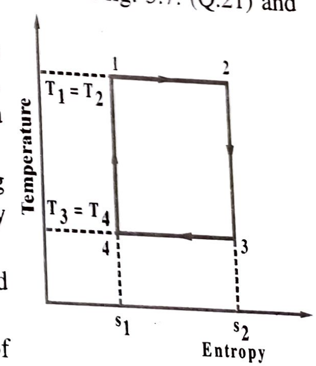


Fig. 5.8 T-s Diagram

Let us assume that the engine works between two sources of infinite heat capacity. One at a lower temperature and the other at a higher temperature.

Assume that the, cylinder contains m kg of air at its original condition represented by point 1 on the p-v and T-s diagrams.

Let, p_1, v_1, T_1 = Pressure, volume and temperature of air at state 1 respectively.

Now, let us consider the four stages of the Carnot's cycle.

(i) ***Process 1-2*** – The hot body (source) at a higher temperature is brought in contact with bottom of the cylinder. The air expands, practically at constant temperature T_1. It may be noted that the heat supplied by the hot body is fully absorbed by the air and is utilised in doing external work.

$\therefore$ Heat supplied = Work done by the air during isothermal expansion

$$Q_{1\text{-}2} = p_1v_1 \log_e\left(\frac{v_2}{v_1}\right) = mRT_1 \log_e\left(\frac{v_2}{v_1}\right) \qquad (\because\ p_1v_1 = mRT_1)$$

or

$$= 2.3\ mRT_1\ \log_{10} r$$

where, r = Expansion ratio = $\dfrac{v_2}{v_1}$.

(ii) ***Process 2-3*** – The hot body or source is removed from the bottom of the cylinder and the insulating cap is brought in contact. The air is now allowed to expand reversibly and adiabatically. The temperature of the air falls from T_2 to T_3. Since no heat absorbed or rejected by the air, therefore,

Decrease in internal energy = Work done by the air during adiabatic expansion

$$= \frac{p_2v_2 - p_3v_3}{\gamma - 1} = \frac{mRT_2 - mRT_3}{\gamma - 1} = \frac{mR(T_1 - T_3)}{\gamma - 1} \qquad (\because\ T_1 = T_2)$$

(iii) ***Process 3-4*** – Now remove the insulating cap from the bottom of the cylinder and bring the cold body in its contact. The air is compressed practically at a constant temperature T_3 from v_3 to v_4. It means that temperature T_4 (at state point 4) is equal to the temperature T_3. It would be seen that during this process, the heat is rejected to cold body and is equal to the work done on the air. Therefore,

Heat rejected = Work done on the air during isothermal compression

$$Q_{3\text{-}4} = p_3v_3 \log_e\left(\frac{v_3}{v_4}\right)$$

$$= mRT_3 \log_e\left(\frac{v_3}{v_4}\right) = 2.3\ mRT_3 \log_{10} r$$

where, r = Compression ratio = $\dfrac{v_3}{v_4}$.

(iv) ***Process 4-1*** – The insulating cap now brought in contact with the bottom of the cylinder, and the air is allowed to be compressed reversibly and adiabatically. The temperature of air increases from T_4 to T_1. Since no heat is absorbed or rejected by the air, therefore,

Increase in internal energy = Work done on the air

$$= \frac{p_1v_1 - p_4v_4}{\gamma - 1} = \frac{mRT_1 - mRT_4}{\gamma - 1} = \frac{mR(T_1 - T_4)}{\gamma - 1}$$

Work done = Heat supplied – Heat rejected

$$= 2.3\ mRT_1\log_{10} r - 2.3\ mRT_3\log_{10} r$$

$$= 2.3\ mR\ \log_{10} r\ (T_1 - T_3)$$

Efficiency of the Carnot cycle,

$$\eta = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{2.3\ mR\log_{10} r\ (T_1 - T_3)}{2.3\ mRT_1\ \log_{10} r} = \frac{T_1 - T_3}{T_1} = 1 - \frac{T_3}{T_1}$$

If we take T_1 (for points 1 and 2) and T_2 (for points 3 and 4) then the efficiency,

$$\eta = \frac{T_1 - T_2}{T_1}$$

It is impossible to make an engine working on Carnot cycle. The reason is that the isothermal expansion 1-2 will have to be carried out extremely slow to ensure that the air is always at temperature T_1. Similarly the isothermal compression 3-4 will have to be carried out extremely slow. But reversible adiabatic expansion 2-3 and reversible adiabatic compression 4-1 should be carried out as quickly as possible, in order to approach ideal adiabatic conditions. Sudden changes in the speed of an engine are not possible in actual practice. It is impossible to completely eliminate friction between the various moving parts of the engine, and also heat losses due to conduction, radiation etc. It is thus obvious that it is impossible to realise Carnot's engine in actual practice.

Q.24. Which is the more effective way to increase the efficiency of a Carnot engine –

To increase T_1 keeping T_2 constant

Or

To decrease T_2 keeping T_1 constant.

where T_1 is source temperature and T_2 is sink temperature.

(R.G.P.V., April 2009)

Ans. The Carnot engine efficiency is given by

$$\eta = 1 - \frac{T_2}{T_1} \qquad \text{...(i)}$$

where, T_1 = Source temperature, T_2 = Sink temperature.

The efficiency of Carnot engine, thus can be increased by decreasing the ratio $\dfrac{T_2}{T_1}$, which can be done either by increasing T_1 or by decreasing T_2.

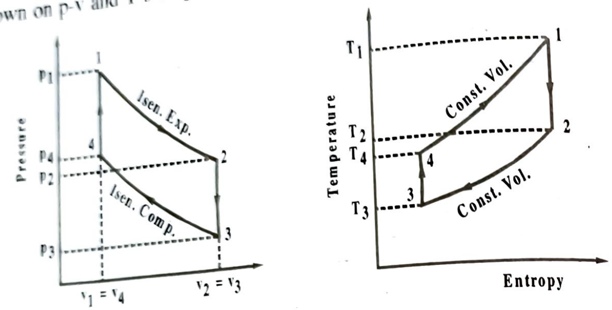
Decreasing T_2 below atmospheric temperature requires special method. Thus, generally T_2, the temperature of low temperature reservoir or sink is fixed by atmospheric or cooling water temperature, and temperature T_1 the temperature of source is increased. This results in increase in Carnot efficiency according to the equation (i). Hence for a fixed lower temperature for heat rejection, the upper temperature at which heat is supplied must be made as high as possible to achieve the maximum efficiency.

Q.25. Explain Otto cycle and derive an expression for efficiency of Otto cycle. *(R.G.P.V., Jan./Feb. 2008, June 2011)*

Or

Derive the expression for air standard efficiency of Otto cycle and show that it depends only on compression ratio. *(R.G.P.V., March/April 2010)*

Ans. Otto cycle is also known as constant volume cycle, as the heat received and rejected at a constant volume. The ideal Otto cycle consists of two constant volume and two reversible adiabatic or isentropic processes as shown on p-v and T-s diagrams in fig. 5.9 (a) and (b) respectively.



(a) p-v Diagram *(b) T-s Diagram*

Fig. 5.9 Otto Cycle

Let, m = Mass of air in cylinder at point 1

p_1, v_1, T_1 = Pressure, volume and temperature of the air respectively at point 1.

(i) ***Process 1-2*** – It is a reversible adiabatic or isentropic expansion process. The air is expanded reversibly and adiabatically from initial temperature T_1 to a temperature T_2. In this process, no heat is absorbed or rejected by the air.

(ii) ***Process 2-3*** – It is a constant volume cooling process. The air is cooled at constant volume from temperature T_2 to a temperature T_3. Heat rejected by the air during this process

$$Q_{2-3} = mc_v(T_2 - T_3)$$

(iii) ***Process 3-4*** – It is a reversible adiabatic or isentropic compression. The air is compressed reversibly and adiabatically from temperature T_3 to a temperature T_4. In this process, no heat is absorbed or rejected by the air.

(iv) ***Process 4-1*** – It is a constant volume heating process. The air is now heated at constant volume from temperature T_4 to a temperature T_1. Heat absorbed by the air during this process,

$$Q_{4-1} = mc_v(T_1 - T_4)$$

$$\text{Work done} = \text{Heat absorbed} - \text{Heat rejected}$$
$$= mc_v(T_1 - T_4) - mc_v(T_2 - T_3)$$

Ideal efficiency or air standard efficiency,

$$\eta = \frac{\text{Work done}}{\text{Heat absorbed}}$$

$$= \frac{mc_v(T_1 - T_4) - mc_v(T_2 - T_3)}{mc_v(T_1 - T_4)}$$

$$= 1 - \frac{T_2 - T_3}{T_1 - T_4} = 1 - \frac{T_3\left(\frac{T_2}{T_3} - 1\right)}{T_4\left(\frac{T_1}{T_4} - 1\right)} \qquad \ldots(i)$$

For reversible adiabatic expansion 1-2,

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} \qquad \ldots(ii)$$

where, r = Expansion ratio $= \frac{v_2}{v_1}$.

Similarly, for reversible adiabatic or isentropic compression process 3-4,

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} \qquad \ldots(iii)$$

where, r = Compression ratio $= \frac{v_3}{v_4} = \frac{v_2}{v_1}$.

From equations (ii) and (iii), we get

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{1}{r}\right)^{\gamma-1} = \frac{1}{(r)^{\gamma-1}} \text{ or } \frac{T_1}{T_4} = \frac{T_2}{T_3}$$

Substituting the value of T_1/T_4 in equation (i), we get

$$\eta = 1 - \frac{T_3}{T_4} = 1 - \frac{T_2}{T_1} = 1 - \frac{1}{(r)^{\gamma-1}} \qquad \left(\because \frac{T_3}{T_4} = \frac{T_2}{T_1}\right) \qquad \ldots(iv)$$

We see from equation (iv) that the efficiency of Otto cycle depends on compression ratio (r) only. The efficiency increases with the increase in compression ratio. In actual practice, r cannot be increased beyond a value of 7 or so.

Compression ratio,

$$r = \frac{\text{Total cylinder volume}}{\text{Clearance volume}}$$

$$= \frac{\text{Clearance volume + Stroke volume}}{\text{Clearance volume}} = \frac{v_c + v_s}{v_c}$$

$\therefore$ Clearance volume, $$v_c = \frac{\text{Stroke volume}}{r - 1} = \frac{v_s}{r - 1}$$

p-v-T relationships for the reversible adiabatic process are,

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} \text{ and } \frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^{\gamma} \text{ or } \frac{v_1}{v_2} = \left(\frac{p_2}{p_1}\right)^{1/\gamma}$$

Q.26. Explain Diesel cycle and derive an expression for efficiency of Diesel cycle. **(R.G.P.V., June 2008)**

Ans. The Diesel cycle consists of two reversible adiabatic or isentropic, a constant pressure and a constant volume processes. These processes are represented on p-v and T-s diagrams in fig. 5.10 (a) and (b) respectively.

Let. m = Mass of air in cylinder

p_1, v_1, T_1 = Pressure, volume and temperature of air respectively at point 1.

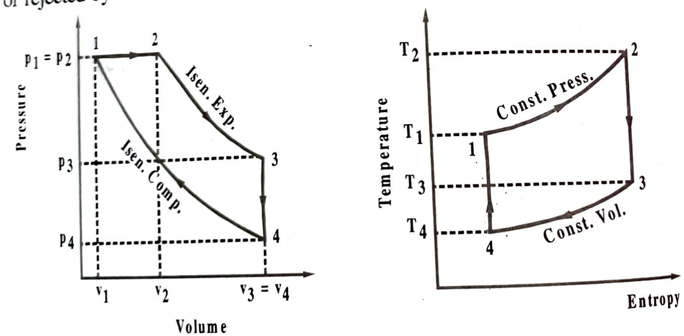
(i) Process 1-2 – It is a constant pressure heating process. The air is heated at constant pressure from initial temperature T_1 to temperature T_2.

∴ Heat supplied to the air,

$$Q_{1\text{-}2} = mc_p\,(T_2 - T_1)$$

Since the supply of heat is cut-off at point 2, therefore it is known as cut-off point.

(ii) Process 2-3 – The air is expanded reversibly and adiabatically from temperature T_2 to a temperature T_3. In this process, no heat is absorbed or rejected by the air.



(a) p-v Diagram ***(b) T-s Diagram***

Fig. 5.10 Diesel Cycle

(iii) Process 3-4 – The air is cooled at constant volume from temperature T_3 to a temperature T_4.

Heat rejected by the air,

$$Q_{3\text{-}4} = mc_v(T_3 - T_4)$$

(iv) Process 4-1 – The air is compressed reversibly and adiabatically from temperature T_4 to a temperature T_1. In this process no heat is absorbed or rejected by the air.

Work done = Heat absorbed – Heat rejected

$$= mc_p\,(T_2 - T_1) - mc_v\,(T_3 - T_4)$$

Air standard efficiency,

$$\eta = \frac{\text{Work done}}{\text{Heat absorbed}} = \frac{mc_p(T_2 - T_1) - mc_v(T_3 - T_4)}{mc_p(T_2 - T_1)}$$

$$= 1 - \frac{c_v}{c_p}\left(\frac{T_3 - T_4}{T_2 - T_1}\right) = 1 - \frac{1}{\gamma}\left(\frac{T_3 - T_4}{T_2 - T_1}\right) \quad \text{.... (i)}$$

Let compression ratio, $r = \dfrac{v_4}{v_1}$ and cut-off ratio, $\rho = \dfrac{v_2}{v_1}$.

Expansion ratio, $r_1 = \dfrac{v_3}{v_2} = \dfrac{v_4}{v_2} = \dfrac{v_4}{v_1} \times \dfrac{v_1}{v_2} = r \times \dfrac{1}{\rho} = \dfrac{r}{\rho}$ $(\because v_3 = v_4)$

For constant pressure heating process 1-2,

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

$$\therefore T_2 = T_1 \times \frac{v_2}{v_1} = T_1 \times \rho \quad \text{....(ii)}$$

For reversible adiabatic expansion process 2-3,

$$\frac{T_3}{T_2} = \left(\frac{v_2}{v_3}\right)^{\gamma-1} = \left(\frac{1}{r_1}\right)^{\gamma-1} = \left(\frac{\rho}{r}\right)^{\gamma-1} \quad \text{....(iii)}$$

For reversible adiabatic compression process 4-1,

$$\frac{T_1}{T_4} = \left(\frac{v_4}{v_1}\right)^{\gamma-1} = (r)^{\gamma-1}$$

or $$T_1 = T_4\,(r)^{\gamma - 1} \quad \text{....(iv)}$$

Now from equations (ii), (iii) and (iv), we get

$$T_2 = T_4\,(r)^{\gamma-1} \times \rho$$

and $$T_3 = T_4(r)^{\gamma-1} \times \rho\left(\frac{\rho}{r}\right)^{\gamma-1} = T_4\rho^{\gamma}$$

Substituting the values of T_1, T_2 anu T_3 in equation (i), we get

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{(T_4\rho^{\gamma}) - T_4}{T_4(r)^{\gamma-1}\rho - T_4(r)^{\gamma-1}}\right] = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right]$$

Q.27. Compare Otto and Diesel cycles. **(R.G.P.V., June 2016)**

Or

Differentiate between an Otto cycle and a Diesel cycle. **(R.G.P.V., Dec. 2010)**

Or

Explain the fundamental difference between Otto and Diesel cycle.

(R.G.P.V., Dec. 2014)

Ans. The basic differences between an Otto cycle and a Diesel cycle are given below –

S.No.	*Otto Cycle*	*Diesel Cycle*
(i)	In Otto cycle both heat addition and rejection take place at constant volume.	In Diesel cycle heat addition takes place at constant pressure while heat rejection takes place at constant volume.
(ii)	Higher air standard efficiency.	Lower air standard efficiency.
(iii)	Efficiency depends only upon compression ratio.	Efficiency depends upon compression ratio and cut-off ratio both.
(iv)	Efficiency does not depend upon load.	Efficiency depends upon load and increases as the load is decreased.

Q.28. What is cut-off ratio ? How does it affect the air standard efficiency of an Otto cycle ? **(R.G.P.V., Dec. 2015)**

Ans. In Diesel cycles, heat is added at constant pressure, during which volume of air increases from v_1 to v_2. After that air expands adiabatically. The point at which heat addition is stopped is called as point of cut-off and the ratio of volume of air at cut-off to the volume at clearance is known as cut-off ratio, mathematically,

$$\text{Cut-off ratio, } \rho = \frac{\text{Volume at cut-off}}{\text{Volume at clearance}}$$

The air standard efficiency of Otto cycle depends only on the compression ratio, thus cut-off does not affect it.

Q.29. Explain the effect of cut-off ratio over the efficiency of a Diesel cycle.

Ans. The efficiency of the Diesel cycle increases with decrease in cut-off ratio and approaches maximum or equal to Otto cycle efficiency when the term $\left[\dfrac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$ of the equation of air standard efficiency of Diesel engine is unity.

Q.30. Explain dual cycle with the help of p-v and T-s diagram and derive expression for its air standard efficiency.

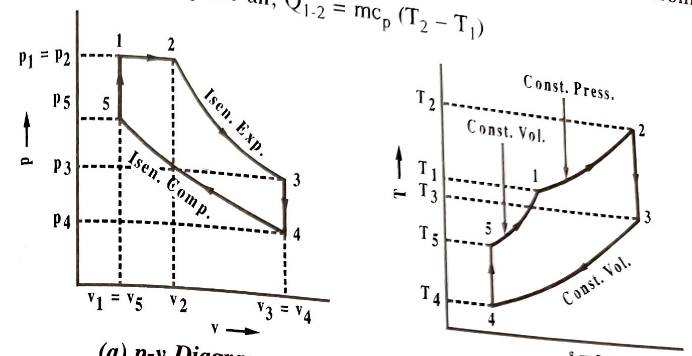
Ans. Dual cycle is sometimes called semi-diesel cycle. It is a combination of Otto and Diesel cycles. The Dual cycle consists of two reversible adiabatic, two constant volume and a constant pressure processes. The Dual cycle on p-v and T-s diagrams is shown in fig. 5.11 (a) and (b) respectively.

Let, m = Mass of the air in engine cylinder in kg

p_1, v_1, T_1 = Pressure, volume and temperature of the air respectively at point 1.

(i) Process 1-2 – The air is heated at constant pressure from temperature T_1 to T_2.

Heat absorbed by the air, $Q_{1-2} = mc_p (T_2 - T_1)$



(a) p-v Diagram **(b) T-s Diagram**

Fig. 5.11 Dual Cycle

(ii) Process 2-3 – The air is expanded reversibly and adiabatically from temperature T_2 to a temperature T_3. In this process, no heat is absorbed or rejected by the air.

(iii) Process 3-4 – The air is cooled at constant volume from temperature T_3 to T_4.

Heat rejected by the air, $Q_{3-4} = m\, c_v (T_3 - T_4)$

(iv) Process 4-5 – The air is compressed reversibly and adiabatically from temperature T_4 to T_5. In this process no heat is absorbed or rejected by the air.

(v) Process 5-1 – The air is finally heated at constant volume from temperature T_5 to T_1.

Heat absorbed by the air

$$Q_{5-1} = mc_v (T_1 - T_5)$$

Work done = Heat absorbed – Heat rejected

$$= [mc_p (T_2 - T_1) + mc_v (T_1 - T_5)] - mc_v (T_3 - T_4)$$

and air standard efficiency of the dual cycle

$$\eta = \frac{\text{Work done}}{\text{Heat absorbed}} = \frac{[mc_p(T_2-T_1)+mc_v(T_1-T_5)]-mc_v(T_3-T_4)}{mc_p(T_2-T_1)+mc_v(T_1-T_5)}$$

$$= 1-\frac{c_v(T_3-T_4)}{c_p(T_2-T_1)+c_v(T_1-T_5)} = 1-\frac{T_3-T_4}{\gamma(T_2-T_1)+(T_1-T_5)} \quad \text{....(i)}$$

Let compression ratio, $r = \frac{v_4}{v_5} = \frac{v_3}{v_1}$ $(\because v_3 = v_4 \text{ and } v_5 = v_1)$

and cut-off ratio, $\rho = \frac{v_2}{v_1} = \frac{v_2}{v_5}$ and pressure ratio, $\alpha = \frac{p_1}{p_5}$.

For a constant pressure heating process 1-2, by Charle's law

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

Therefore, $T_2 = T_1 \times \frac{v_2}{v_1} = T_1\rho$ ....(ii)

Similarly, in reversible adiabatic or isentropic expansion process 2-3,

$$\frac{T_3}{T_2} = \left(\frac{v_2}{v_3}\right)^{\gamma-1} = \left(\frac{v_2}{v_1} \times \frac{v_1}{v_3}\right)^{\gamma-1} = \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$\therefore$ $$T_3 = T_2\left(\frac{\rho}{r}\right)^{\gamma-1} = T_1\rho\left(\frac{\rho}{r}\right)^{\gamma-1} \quad ....(iii)$$

For reversible adiabatic compression process 4-5,

$$\frac{T_5}{T_4} = \left(\frac{v_4}{v_5}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$\therefore$ $$T_5 = T_4(r)^{\gamma-1} \quad ....(iv)$$

For constant volume heating process 5-1,

$$\frac{p_5}{T_5} = \frac{p_1}{T_1} \quad \text{(by Gay-Lussac law)}$$

Therefore, $T_1 = T_5 \times \frac{p_1}{p_5} = T_5\alpha = T_4(r)^{\gamma-1}\alpha$ ...(v)

Substituting the value of T_1 in equations (ii) and (iii), we get

$$T_2 = T_4(r)^{\gamma-1}\alpha\rho$$

and $$T_3 = T_4(r)^{\gamma-1}\alpha\rho\left(\frac{\rho}{r}\right)^{\gamma-1} = T_4\alpha\rho^{\gamma}$$

Substituting the values of T_1, T_2, T_3 and T_5 in equation (i), we get

$$\eta = 1 - \frac{T_4\alpha\rho^{\gamma} - T_4}{\gamma[T_4(r)^{\gamma-1}\alpha\rho - T_4(r)^{\gamma-1}\alpha] + [T_4(r)^{\gamma-1}\alpha - T_4(r)^{\gamma-1}]}$$

$$= 1 - \frac{T_4(\alpha\rho^{\gamma} - 1)}{T_4(r)^{\gamma-1}[\gamma(\alpha\rho - \alpha) + (\alpha - 1)]}$$

$$= 1 - \frac{(\alpha\rho^{\gamma} - 1)}{(r)^{\gamma-1}[\gamma\alpha(\rho - 1) + (\alpha - 1)]} = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{(\alpha\rho^{\gamma} - 1)}{(\alpha - 1) + \gamma\alpha(\rho - 1)}\right]$$

Q.31. With the help of p-v and T-s diagrams, show that for the same maximum pressure and heat input

$$\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}$$

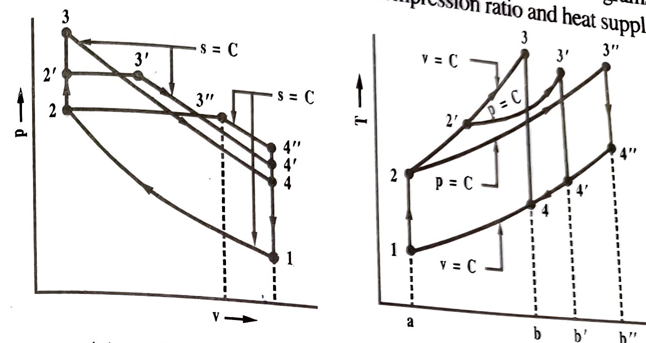
(R.G.P.V., Dec. 2015)

Or

For the same compression ratio and heat supplied, state the order of decreasing air standard efficiency of Otto, Diesel and Dual cycle.

(R.G.P.V., June 2014)

Ans. The Otto, Diesel and Dual cycles are shown on p-v and T-s diagrams in fig. 5.12 (a) and (b) respectively for the same compression ratio and heat supplied.



(a) p-v Diagram

(b) T-s Diagram

Fig. 5.12 Comparison of Otto, Diesel and Dual Cycle

The Otto cycle is shown by the area 1-2-3-4, the Dual cycle as 1-2-2'-3'-4' and the Diesel cycle as 1-2-3"-4". All the three cycles start at the same initial temperature, pressure and volume at point 1. The air is compressed isentropically from state point 1 to state point 2. Heat is added under varying conditions for the different cycles. For equal heat supplied, the T-s areas a-2-3-b, a-2-2'-3'-b' and a-2-3"-b" must be equal. Since constant volume lines are steeper on the T-s diagram than constant pressure line, construction of equal areas for the heat supplied shows point 3" will lie at the point of greatest entropy. With isentropic expansion to the constant volume line 1-4", the rejected heat for each cycle is shown as the approximate area under line 1-4". As the same amount of heat is supplied to each cycle, the cycle which rejects least amount of heat after expansion will be more efficient.

Thermal efficiency, $\eta_{th} = 1 - \frac{Q_R}{Q_A} = 1 - \frac{Q_R}{\text{Constant}}$

We see that the Otto cycle rejects least amount of heat shown by the area a-1-4-b. Thus the Otto cycle has maximum efficiency. The order of the efficiencies for the three cycles is given as

$$(\eta_{th})_{Otto} > (\eta_{th})_{Dual} > (\eta_{th})_{Diesel}$$

Numerical Problems

***Prob.5.** A reversible heat engine delivers 0.6 kW power and rejects heat energy to a reservoir at 300 K at the rate of 24 kJ/min. Determine the cycle efficiency and temperature of the thermal reservoir supplying heat to the engine.*
(R.G.P.V., June 2012)

Sol. Given. $W_{net} = 0.6$ kW. $Q_R = 24$ kJ/min $= 24/60 = 0.4$ kJ/s $= 0.4$ kW. $T_2 = 300$ K.

The given heat engine system is shown in fig. 5.13.

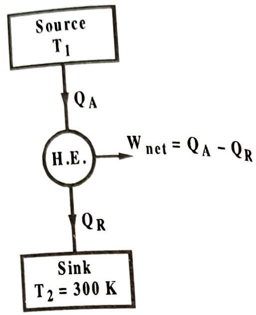


Fig. 5.13

Heat absorbed by heat engine or heat supplied by source reservoir,

$$Q_A = W_{net} + Q_R$$
$$= 0.6 + 0.4 = 1 \text{ kW}$$

Thus, thermal efficiency of the engine,

$$\eta = \frac{W_{net}}{Q_A} = \frac{0.6}{1} = 0.6 \text{ or } \mathbf{60\%} \quad \textbf{Ans.}$$

Thermal efficiency of the engine is also given as,

$$\eta = 1 - \frac{T_2}{T_1}$$

$$0.6 = 1 - \frac{300}{T_1}$$

or $$\frac{300}{T_1} = 1 - 0.6 = 0.4$$

$\therefore$ $$T_1 = \frac{300}{0.4} = \mathbf{750\ K} \quad \textbf{Ans.}$$

***Prob.6.** A Carnot cycle has lowest temperature and pressure as 20°C and 1 bar. Pressure after isothermal compression is 4 bar and after isentropic compression is 12 bar and after isothermal heat addition process is 3 bar. Calculate –*

(i) Heat added in the cycle per kg (ii) Cycle efficiency.

Sol. Given, $p_3 = 1$ bar, $p_4 = 4$ bar, $p_1 = 12$ bar, $p_2 = 3$ bar, $T_3 = T_4 = 20 + 273 = 293$ K.

Applying characteristic gas equation at point 3, we have

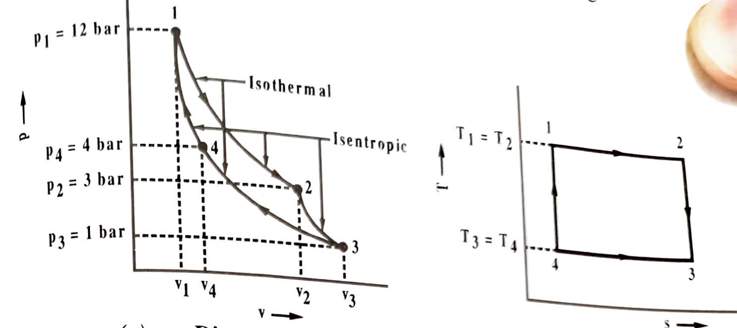
$$v_3 = \frac{RT_3}{p_3} = \frac{0.287 \times 293}{1 \times 10^2} = 0.84091 \text{ m}^3/\text{kg}$$

For isothermal heat rejection process 3-4, we have

$$v_4 = \frac{p_3 v_3}{p_4} = \frac{1 \times 10^2 \times 0.84091}{4 \times 10^2} = 0.2102 \text{ m}^3/\text{kg}$$

For isentropic compression process 4-1, we have

$$v_1 = v_4\left(\frac{p_4}{p_1}\right)^{1/\gamma} = 0.2102\left(\frac{4}{12}\right)^{1/1.4} = 0.0959 \text{ m}^3/\text{kg}$$



(a) p-v Diagram *(b) T-s Diagram*

Fig. 5.14 Carnot Cycle

$\therefore$ Stroke volume, $v_s = v_3 - v_1 = 0.84091 - 0.0959 = 0.745$ m³/kg

Again $$T_1 = T_3\left(\frac{v_4}{v_1}\right)^{\gamma-1} = 293\left(\frac{0.2102}{0.0959}\right)^{0.4} = 401.045 \text{ K}$$

From isothermal heat addition process 1-2, we have

$$v_2 = v_1\left(\frac{p_1}{p_2}\right) = 0.0959\left(\frac{12}{3}\right) = 0.3836 \text{ m}^3/\text{kg}$$

Heat added in the cycle per kg

$$q_A = p_1 v_1 ln\left(\frac{v_2}{v_1}\right)$$

$$= 12 \times 10^2 \times 0.0959\, ln\left(\frac{0.3836}{0.0959}\right) = \mathbf{159.535\ kJ/kg} \quad \textbf{Ans.}$$

$$\text{Cycle efficiency} = 1 - \frac{T_3}{T_1} = 1 - \frac{293}{401.045} = 0.2694 \text{ or } \mathbf{26.94\%} \quad \textbf{Ans.}$$

***Prob.7.** In an engine working on ideal Otto cycle, the temperature at the beginning and at the end of compression are 27°C and 327°C. Find the compression ratio and air standard efficiency of the engine.*
(R.G.P.V., June 2011)

Sol. Given, $t_3 = 27$°C or $T_3 = 27 + 273 = 300$ K, $t_4 = 327$°C or $T_4 = 327 + 273 = 600$ K.

For isentropic compression process 3-4,

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1} = (r)^{\gamma-1}$$

(∵ For air, $\gamma = 1.4$)

$$\frac{600}{300} = (r)^{1.4-1}$$

$$2 = (r)^{0.4}$$

or $$r = (2)^{1/0.4} = \mathbf{5.657}$$ **Ans.**

Air standard efficiency of Otto engine,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$= 1 - \frac{1}{(5.657)^{1.4-1}} = 1 - \frac{1}{2} = 0.5 \text{ or } \mathbf{50\%}$$ **Ans.**

Prob.8. ***Calculate the efficiency of the following ideal cycles when undergone by a perfect gas with a γ value of 1.4 –***

(i) A Sterling cycle operating between a hot reservoir at 600 K and a cold reservoir at 300 K.

(ii) An Otto cycle with a compression ratio of 9.

(iii) A Diesel cycle with a compression ratio of 12 and a cut-off ratio of 2. ***(R.G.P.V., June 2016)***

Sol. (i) Sterling Cycle

Given, $T_1 = 600$ K, $T_3 = 300$ K.

Air standard efficiency of Sterling cycle is given as

$$\eta = 1 - \frac{T_3}{T_1} = 1 - \frac{300}{600} = 0.5 \text{ or } \mathbf{50\%}$$ **Ans.**

(ii) Otto Cycle

Given, r = 9.

Air standard efficiency of Otto cycle is given as,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(9)^{1.4-1}}$$

$$= 1 - 0.4152 = 0.5848 \text{ or } \mathbf{58.48\%}$$ **Ans.**

(iii) Diesel Cycle

Given, r = 12, $\rho = 2$.

Air standard efficiency of Diesel cycle is given as

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right] = 1 - \frac{1}{(12)^{1.4-1}}\left[\frac{2^{1.4}-1}{1.4(2-1)}\right]$$

$$= 1 - 0.4333 = 0.5667 \text{ or } \mathbf{56.67\%}$$ **Ans.**

Prob.9. The minimum pressure and temperature in a Otto cycle are 100 kPa and 27°C. The amount of heat added to the air per cycle is 1500 kJ/kg. Determine the pressures and temperaures at all points of the air standard Otto cycle. Also calculate the specific work and thermal efficiency of the cycle for compression ratio of 8 : 1. ***(R.G.P.V., June 2014)***

Sol. Given, $p_3 = 100$ kPa $= 1 \times 10^5$ N/m² = 1 bar, $t_3 = 27$°C or $T_3 = 27 + 273 = 300$ K, $Q_{4\text{-}1} = 1500$ kJ/kg, $r = \frac{v_3}{v_4} = \frac{v_2}{v_1} = 8$.

(i) Pressure and temperature at all points

For isentropic compression process 3-4,

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$\frac{300}{T_4} = \left(\frac{1}{8}\right)^{1.4-1}$$ (∵ For air $\gamma = 1.4$)

$$\frac{300}{T_4} = 0.435$$

∴ $$T_4 = \frac{300}{0.435} = \mathbf{689.6\ K}$$ **Ans.**

and $$p_3 v_3^{\gamma} = p_4 v_4^{\gamma}$$

or $$\frac{p_4}{p_3} = \left(\frac{v_3}{v_4}\right)^{\gamma} = (r)^{\gamma}$$

$$\frac{p_4}{1} = (8)^{1.4} = 18.38$$

∴ $$p_4 = 1 \times 18.38 = \mathbf{18.38\ bar}$$ **Ans.**

Heat added during constant volume process 4-1,

$$Q_{4\text{-}1} = mc_v\,(T_1 - T_4)$$

$$1500 = 1 \times 0.713\,(T_1 - 689.6)$$

(∵ For air $c_v = 0.713$ kJ/kg K)

or $$T_1 - 689.6 = 2103.8$$

∴ $$T_1 = \mathbf{2793.4\ K}$$ **Ans.**

Also for constant volume process 4-1,

$$\frac{p_4}{p_1} = \frac{T_4}{T_1}$$

$$\frac{18.38}{p_1} = \frac{689.6}{2793.4} = 0.2469$$

$$\therefore \quad p_1 = \frac{18.38}{0.2469} = \mathbf{74.4\ bar}$$ **Ans.**

Now for isentropic expansion process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$\frac{T_2}{2793.4} = \left(\frac{1}{8}\right)^{1.4-1} = 0.435$$

$$\therefore \quad T_2 = 2793.4 \times 0.435 = \mathbf{1215.1\ K}$$ **Ans.**

Also for process 1-2,

$$p_2 v_2^{\gamma} = p_1 v_1^{\gamma}$$

or

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{\gamma}$$

$$\frac{p_2}{74.4} = \left(\frac{1}{8}\right)^{1.4} = 0.0544$$

$$\therefore \quad p_4 = 74.4 \times 0.0544 = \mathbf{4.05\ bar}$$ **Ans.**

(ii) Specific work

Heat rejected per cycle during process 2-3,

$$Q_{2\text{-}3} = mc_v\,(T_2 - T_3)$$
$$= 1 \times 0.713 \times (1215.1 - 300) = 652.5 \text{ kJ/kg}$$

Thus, specific work

$$= \text{Heat supplied} - \text{Heat rejected}$$
$$= 1500 - 652.5 = \mathbf{847.5\ kJ/kg}$$ **Ans.**

(iii) Thermal efficiency

Efficiency of Otto cycle is given as,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$= 1 - \frac{1}{(8)^{1.4-1}} = 0.5647 \text{ or } \mathbf{56.47\%}$$ **Ans.**

Prob.10. An engine working on Otto cycle is supplied with air at 0.1 MPa and 35°C. The compression ratio is 8. Heat supplied is 2100 kJ/kg. Calculate the maximum pressure and temperature of the cycle, cycle efficiency and mean effective pressure. (R.G.P.V., June 2013)

Sol. Given, $p_3 = 0.1$ MPa $= 1 \times 10^5$ N/m^2, $t_3 = 35°C$ or $T_3 = 273 + 35 = 308$ K, $r = \frac{v_3}{v_4} = \frac{v_2}{v_1} = 8$, $Q_{4\text{-}1} = 2100$ kJ/kg.

(i) Maximum pressure and temperature of the cycle

For isentropic compression process 3-4,

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1}$$

$$\frac{308}{T_4} = \left(\frac{1}{8}\right)^{1.4-1} \qquad (\because \text{For air } \gamma = 1.4)$$

$$\frac{308}{T_4} = 0.435$$

$$\therefore \quad T_4 = \frac{308}{0.435} = 708 \text{ K}$$

and

$$p_3 v_3^{\gamma} = p_4 v_4^{\gamma}$$

or

$$\frac{p_4}{p_3} = \left(\frac{v_3}{v_4}\right)^{\gamma} = (8)^{1.4} = 18.38$$

$$\therefore \quad p_4 = 0.1 \times 10^6 \times 18.38$$
$$= 1.838 \times 10^6 \text{ N/mm}^2 = 18.38 \text{ bar}$$

Heat added during constant volume process 4-1,

$$Q_{4\text{-}1} = mc_v\,(T_1 - T_4)$$
$$2100 = 1 \times 0.713\,(T_1 - 708)$$

or

$$T_1 - 708 = 2945.3$$

$$\therefore \quad T_1 = \mathbf{3653.3\ K}$$ **Ans.**

We know for constant volume process 4-1,

$$\frac{p_4}{p_1} = \frac{T_4}{T_1}$$

$$\frac{18.38}{p_1} = \frac{708}{3653.3} = 0.1938$$

$$\therefore \quad p_1 = \mathbf{94.84\ bar}$$ **Ans.**

(ii) Cycle efficiency

Cycle efficiency of Otto cycle is given as,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$= 1 - \frac{1}{(8)^{1.4-1}} = \mathbf{0.5647\ or\ 56.47\%}$$ **Ans.**

(iii) Mean effective pressure

For isentropic expansion process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$\frac{T_2}{3653.3} = \left(\frac{1}{8}\right)^{1.4-1} = 0.435$$

or $$T_2 = 3653.3 \times 0.435 = 1589.2 \text{ K}$$

Heat rejected per kg of air,

$$Q_{2\text{-}3} = c_v(T_2 - T_3)$$
$$= 0.713(1589.2 - 308) = 913.5 \text{ kJ}$$

From ideal gas equation,

$$p_3v_3 = mRT_3$$
$$1 \times 10^5 \times v_3 = 1 \times 287 \times 308 = 88396$$

($\because$ For air, R = 287 J/kg K)

$\therefore$ $$v_3 = 0.884 \text{ m}^3$$

and $$v_4 = \frac{v_3}{r} = \frac{0.884}{8} = 0.1105 \text{ m}^3$$

Thus, stroke volume $= v_3 - v_4$
$= 0.884 - 0.1105 = 0.7735 \text{ m}^3$

Work done = Heat supplied – Heat rejected
$= 2100 - 913.5 = 1186.5$ kJ

$$\text{Mean effective pressure} = \frac{\text{Work done}}{\text{Stroke volume}}$$
$$= \frac{1186.5}{0.7735}$$
$= 1533.9 \text{ kN/m}^2$ or **15.34 bar** **Ans.**

Prob.11. A gas engine working on Otto cycle operates with the following parameters –

Inlet condition 1 bar pressure 320 K temperature compression ratio 4 : 1 and pressure ratio 4 : 1.

If the working fluid is air with R = 287 J/kgK and γ = 1.4. Make calculation for useful work done, thermal efficiency and mean effective pressure.

(R.G.P.V., Dec. 2015)

Sol. Given, $p_3 = 1 \text{ bar} = 1 \times 10^5 \text{ N/m}^2$, $T_3 = 320$ K, $r = \frac{v_3}{v_4} = \frac{v_2}{v_1} = 4$, $r_p = \frac{p_1}{p_4} = \frac{p_2}{p_3} = 4$, R = 287 J/kg K, $\gamma = 1.4$.

For isentropic compression process 3-4,

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$$\frac{T_4}{320} = (4)^{1.4-1} = 1.74$$

or $$T_4 = 320 \times 1.74 = 556.8 \text{ K}$$

For constant volume process 4-1,

$$\frac{T_1}{T_4} = \frac{p_1}{p_4} = r_p$$

$$\frac{T_1}{556.8} = 4$$

or $$T_1 = 556.8 \times 4 = 2227.2 \text{ K}$$

For isentropic expansion process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$\frac{T_2}{2227.2} = \left(\frac{1}{4}\right)^{1.4-1} = 0.5743$$

or $$T_2 = 2227.2 \times 0.5743 = 1279.1 \text{ K}$$

(i) Useful work done

Heat supplied during constant volume process 4-1,

$$Q_{4\text{-}1} = mc_v(T_1 - T_4)$$
$$= m.\frac{R}{\gamma - 1}(T_1 - T_4) \left[\because c_p - c_v = R \text{ and } \frac{c_p}{c_v} = \gamma\right]$$
$$= 1 \times \frac{287}{1.4 - 1} \times (2227.2 - 556.8)$$
$$= 1198512 \text{ J/kg} \simeq 1198.5 \text{ kJ/kg}$$

Heat rejected during process 2-3,

$$Q_{2\text{-}3} = mc_v(T_2 - T_3)$$
$$= 1 \times \frac{287}{1.4 - 1}(1279.1 - 320)$$
$$= 688154.25 \text{ J/kg} \simeq 688.15 \text{ kJ/kg}$$

$\therefore$ Useful work done $= \text{Heat supplied} - \text{Heat rejected}$

$= 1198.5 - 688.15 = \mathbf{510.35\ kJ/kg}$ **Ans.**

(ii) Thermal efficiency

Efficiency of Otto cycle is given by

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(4)^{1.4-1}}$$

$$= 1 - 0.5743 = 0.4257 \text{ or } \mathbf{42.57\%}$$ **Ans.**

(iii) Mean effective pressure

From ideal gas equation,

$$p_3 v_3 = mRT_3$$

$$1 \times 10^5 \times v_3 = 1 \times 287 \times 320 = 91840$$

$$v_3 = 0.9184 \text{ m}^3$$

and $\therefore$

$$v_4 = \frac{v_3}{r} = \frac{0.9184}{4} = 0.2296 \text{ m}^3$$

Thus stroke volume $= v_3 - v_4$

$= 0.9184 - 0.2296 = 0.6888 \text{ m}^3$

Mean effective pressure

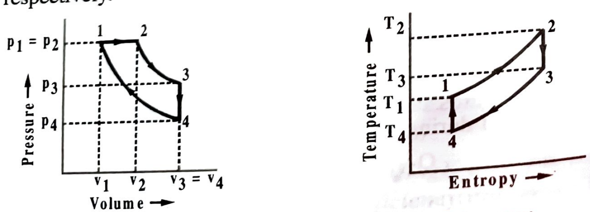
$$= \frac{\text{Work done}}{\text{Stroke volume}} = \frac{510.35}{0.6888}$$

$= 740.93 \text{ kN/m}^2$ or **7.4 bar** **Ans.**

Prob.12. Find the power output of a Diesel engine working on a diesel cycle with compression ratio of 16 and air flow rate of 0.25 kg/s, the initial condition of air at 1 bar absolute and 27°C temperature, heat added per cycle 2500 kJ/kg. ***(R.G.P.V., June 2014)***

Sol. Given, $r = 16$, $m = 0.25$ kg/s, $p_4 = 1$ bar, $t_4 = 27°C$ or $T_4 = 27 + 237 = 300$ K, $Q_{1\text{-}2} = 2500$ kJ/kg.

The p-v and T-s diagrams for the Diesel cycle are shown in fig. 5.15 (a) and (b) respectively.



(a) p-v Diagram *(b) T-s Diagram*

Fig. 5.15

For isentropic compression process 4-1,

$$p_4 v_4^{\gamma} = p_1 v_1^{\gamma}$$

or

$$p_1 = p_4 \left(\frac{v_4}{v_1}\right)^{\gamma} = p_4 (r)^{\gamma}$$

$$p_1 = 1 \times (16)^{1.4} = 48.5 \text{ bar}$$

Also for process 4-1,

$$\frac{p_1}{p_4} = \left(\frac{T_1}{T_4}\right)^{\frac{\gamma}{\gamma-1}}$$

or

$$\frac{T_1}{T_4} = \left(\frac{p_1}{p_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_1}{300} = \left(\frac{48.5}{1}\right)^{\frac{1.4-1}{1.4}} = 3.03$$

$\therefore$

$$T_1 = 300 \times 3.03 = 909 \text{ K}$$

From ideal gas equation,

$$p_4 v_4 = mRT_4$$

or

$$v_4 = \frac{mRT_4}{p_4}$$

$$= \frac{1 \times 287 \times 300}{1 \times 10^5} \quad (\because \text{For air, } R = 287 \text{ J/kg K})$$

$$= 0.861 \text{ m}^3$$

and

$$v_1 = \frac{v_4}{r} = \frac{0.861}{16} = 0.0538 \text{ m}^3$$

Heat supplied per kg of air during constant pressure process 1-2,

$$Q_{1\text{-}2} = mCp\,(T_2 - T_1)$$

$$2500 = 1 \times 1 \times (T_2 - 909) (\because \text{For air, } C_p = 1 \text{ kJ/kg K})$$

or

$$T_2 - 909 = 2500$$

$\therefore$

$$T_2 = 3409 \text{ K}$$

For constant pressure process 1-2,

$$\frac{v_1}{v_2} = \frac{T_1}{T_2}$$

$$\frac{0.0538}{v_2} = \frac{909}{3409}$$

$$v_2 = \frac{3409}{909} \times 0.0538 = 0.2018 \text{ m}^3$$

or

For isentropic expansion process 2-3,

$$\frac{T_2}{T_3} = \left(\frac{v_3}{v_2}\right)^{\gamma-1} = \left(\frac{v_4}{v_2}\right)^{\gamma-1} \qquad (\because v_3 = v_4)$$

$$\frac{3409}{T_3} = \left(\frac{0.861}{0.2018}\right)^{1.4-1} = 1.7866$$

$$\therefore \quad T_3 = \frac{3409}{1.7866} = 1908.1 \text{ K}$$

Heat rejected per kg of air during the constant volume process 3-4,

$$Q_{3\text{-}4} = mC_v(T_3 - T_4)$$

$$= 1 \times 0.713 \times (1908.1 - 300)$$

$$(\because \text{For air, } C_v = 0.713 \text{ kJ/kg K})$$

$$= 1146.58 \text{ kJ/kg}$$

Power developed,

$$P = 0.25 \text{ (Heat supplied} - \text{Heat rejected)}$$

$$= 0.25\ (2500 - 1146.58) = 338.355 \text{ kJ/s}$$

and actual power output,

$$P' = \eta_{Diesel} \times P$$

$$= \left(1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}\right) \times P$$

$$= \left(1 - \frac{1146.58}{2500}\right) \times 338.355$$

$$= 183.2 \text{ kJ/s or } \mathbf{183.2 \text{ kW}}$$

Ans.

Prob.13. For an air standard dual cycle, the following data are available –

Air intake at 1 bar and 323 K

Maximum pressure is 70 bar

Heat addition at constant pressure = Heat addition at constant volume.

Determine –

(i) Pressure and temperatures at all the points of the cycle

(ii) Cycle efficiency (iii) m.e.p.

Sol. Given, $p_4 = 1$ bar, $T_4 = 323$ K, $p_1 = p_2 = 70$ bar.

(i) Pressure and temperatures at all points

Let compression ratio,

$$r = \frac{v_4}{v_5} = 16$$

Also let, T_5 = Temperature at the end of isentropic compression.

For isentropic compression process 4-5,

$$\frac{T_5}{T_4} = \left(\frac{v_4}{v_5}\right)^{\gamma-1}$$

$$\frac{T_5}{323} = (16)^{1.4-1} \qquad (\because \text{For air } \gamma = 1.4)$$

$$\therefore \quad T_5 = 323 \times (16)^{0.4} = \mathbf{979.1 \text{ K}}$$

Ans.

Again for process 4-5,

$$\frac{p_5}{p_4} = \left(\frac{v_4}{v_5}\right)^{\gamma}$$

$$\frac{p_5}{1} = (16)^{1.4} = 48.5$$

$$\therefore \quad p_5 = \mathbf{48.5 \text{ bar}}$$

Ans.

For constant volume heating process 5-1,

$$\frac{T_1}{T_5} = \frac{p_1}{p_5}$$

$$\frac{T_1}{979.1} = \frac{70}{48.5}$$

or

$$T_1 = \frac{70}{48.5} \times 979.1 = \mathbf{1413.1 \text{ K}}$$

Ans.

Now according to given condition,

Heat addition at constant pressure = Heat addition at constant volume

$$Q_{1\text{-}2} = Q_{5\text{-}1}$$

$$mc_p\,(T_2 - T_1) = mc_v\,(T_1 - T_5)$$

For air $c_p = 1.005$ kJ/kg K and $c_v = 0.718$ kJ/kg K, therefore

$$1.005\ (T_2 - 1413.1) = 0.718\ (1413.1 - 979.1)$$

$$T_2 - 1413.1 = \frac{0.718}{1.005} \times 434 = 310$$

or

$$T_2 = 310 + 1413.1 = \mathbf{1723.1 \text{ K}}$$

Ans.

For constant pressure heating process 1-2,

$$\frac{v_2}{v_1} = \frac{T_2}{T_1} = \frac{1723.1}{1413.1} = 1.22$$

Now

$$\frac{v_3}{v_2} = \frac{v_3}{v_1} \times \frac{v_1}{v_2} = \frac{v_4}{v_5} \times \frac{v_1}{v_2} \qquad (\because v_3 = v_4 \text{ and } v_1 = v_5)$$

$$= 16 \times \frac{1}{1.22} = 13.1$$

For isentropic expansion process 2-3,

$$\frac{T_2}{T_3} = \left(\frac{v_3}{v_2}\right)^{\gamma-1}$$

$$\frac{1723.1}{T_3} = (13.1)^{1.4-1} = 2.8$$

$\therefore$ $$T_3 = \frac{1723.1}{2.8} = \mathbf{615.4\ K}$$ **Ans.**

For constant volume process 3-4,

$$\frac{p_3}{p_4} = \frac{T_3}{T_4}$$

$$\frac{p_3}{1} = \frac{615.4}{323}$$

$\therefore$ $$p_3 = \mathbf{1.9\ bar}$$ **Ans.**

(ii) Cycle efficiency

Cycle efficiency of dual cycle will be

$$\eta = 1 - \frac{T_3 - T_4}{\gamma(T_2 - T_1) + (T_1 - T_5)}$$

$$= 1 - \frac{615.4 - 323}{1.4\,(1723.1 - 1413.1) + (1413.1 - 979.1)}$$

$$= 1 - \frac{292.4}{434 + 434} = 0.663 \text{ or } \mathbf{66.3\%}$$ **Ans.**

(iii) m.e.p.

Net work done,

$$W_{net} = \eta \times \text{Heat added}$$
$$= \eta \times [c_v\,(T_1 - T_5) + c_p\,(T_2 - T_1)]$$
$$= 0.663 \times [0.718\,(1413.1 - 979.1) + 1.005\,(1723.1 - 1413.1)]$$
$$= 0.663 \times 623.162 = 413.16 \text{ kJ/kg}$$

From gas equation,

$$v_4 = \frac{RT_4}{p_4} = \frac{0.287 \times 323}{1 \times 10^2} \qquad \left(\begin{array}{l}\because \text{For air, } R = 0.287 \text{ kJ/kg K} \\ p_4 = 1 \text{ bar} = 1 \times 10^2 \text{ kN/m}^2\end{array}\right)$$
$$= 0.927 \text{ m}^3\text{/kg}$$

Thus,

$$v_4 - v_5 = v_4 - \frac{v_4}{16} \qquad \left(\because \frac{v_4}{v_5} = 16\right)$$

$$= \frac{15}{16} \times v_4 = \frac{15}{16} \times 0.927 = 0.869 \text{ m}^3\text{/kg}$$

Now m.e.p. of cycle,

$$p_m = \frac{W_{net}}{v_4 - v_5} = \frac{413.16}{0.869} = 475.4 \text{ kN/m}^2 \simeq \mathbf{4.75\ bar}$$ **Ans.**

WORKING OF TWO-STROKE & FOUR-STROKE PETROL & DIESEL ENGINES

Q.32. What are internal combustion engines ?

Ans. In internal combustion (I.C.) engines, fuel and air are mixed together and combustion takes place within the engine, the products of combustion act as a working fluid. These products of combustion are exhausted at the end of each stroke.

The I.C. engines are much compact than external combustion engines (e.g. steam engine) for the same power generation, that is why they are best suited for automobiles, scooters, power boats, ships, slow speed aircrafts, locomotives and power units of relatively small output. The thermal efficiency of I.C. engines is much higher than that of steam engines. A best modern I.C. engine can convert about 30-35% of heat of combustion of fuel into useful work. Very high temperatures are produced in the I.C. engine cylinder, thus they have to be cooled artificially by means of air or water circulating around the cylinder.

Q.33. Give the differences between internal combustion engines and steam engines. ***(R.G.P.V., Dec. 2004)***

Ans. The differences between internal combustion engines and steam engines are given as follows –

S.No.	*Internal Combustion Engine*	*Steam Engine*
(i)	The combustion of fuel takes place inside the engine cylinder.	The combustion of fuel takes place outside the engine cylinder.
(ii)	The I.C. engines have efficiency about 35-40%.	The steam engines have efficiency about 15-20%.
(iii)	It can be started instantaneously.	It cannot be started instantaneously.
(iv)	Since combustion of fuel takes place inside the engine cylinder, these engines are very noisy.	Since combustion of fuel takes place outside the engine cylinder, therefore these engines are smooth and silent running.
(v)	Because of very high pressure and temperature, special alloys are used for the manufacture of engine cylinder and its parts.	Because of low pressure and temperature, ordinary alloys are used for the manufacture of engine cylinder and its parts.
(vi)	An I.C. engine does not require a boiler or other components. Thus it is light and compact.	A steam engine requires a boiler and other components to transfer energy. Thus it is cumbersome.
(vii)	The working pressure and temperature inside the cylinder is very high.	The working pressure and temperature inside the engine cylinder is low.

Q.34. Give classification of I.C. engines.

Ans. I.C. engines can be classified in following ways –

(i) Type of Fuel Used – I.C. engines can use only liquid or gaseous fuels, depending upon the type of fuel used they can be classified as –

(a) Petrol engines (b) Diesel engines
(c) Gas engines (d) Dual-fuel engines.

(ii) Number of Strokes – Depending upon the number of strokes required to complete a working cycle, I.C. engines can be classified as –

(a) Four-stroke engines (b) Two-stroke engines.

(iii) Cycle of Operation – According to the thermodynamic cycle of operation, I.C. engines can be classified as –

(a) Otto cycle engine, in which heat addition takes place at constant volume. This cycle is used for petrol engines.

(b) Diesel cycle engine, in which heat addition takes place at constant pressure. This cycle is used for diesel engines.

(c) Dual cycle engine, in which heat addition partly takes place at constant volume and partly at constant pressure.

(iv) Method of Ignition – Depending upon the method of ignition used to ignite the fuel-air mixture, I.C. engines can be classified as –

(a) Spark ignition (S.I.) engines
(b) Compression ignition (C.I.) engines.

(v) Type of Cooling System Used – As high temperatures are generated in I.C. engine cylinders, thus it is necessary to artificially cool them. Depending upon the cooling system used, I.C. engines can be classified as –

(a) Air cooled engines (b) Water cooled engines.

(vi) Number of Cylinders –

(a) Single cylinder engines (b) Twin cylinder engines
(c) Multi cylinder engines etc.

Q.35. Explain with figure why steam engines have a crosshead but I.C. engines do not have. **(R.G.P.V., Dec. 2005)**

Ans. In steam engine (as shown in fig. 5.2), the reciprocating piston is converted into the rotary motion of crank by means of the connecting rod. The connecting rod is connected to the piston rod by means of an intermediate link, which is known as crosshead. The function of the crosshead is to guide the motion of the piston rod and to prevent it from bending.

While, in I.C. engine (as shown in fig. 5.16) the connecting rod which converts reciprocating motion of piston into rotary motion of crank, is directly connected to the piston by means of a gudgeon pin. Thus, there is no need of a crosshead in I.C. engines.

Q.36. Why cooling of an I.C. engine is required ? (R.G.P.V., June 2015)

Ans. As a result of combustion, the temperature of gases in a reciprocating engine varies from 40°C to 2500°C during the cycle. A large portion of this heat is transferred to the cylinder head and walls, piston and valves. As a result of this temperature of the cylinder and piston may exceed 1500°C. At such high temperatures, the metals will loose their properties and expansion of piston may seize the liner. Some other adverse effects of this heating are given below –

(i) The high temperature reduces the strength of the piston and piston rings and may also damage many parts of the engine.

(ii) The high temperature may cause decomposition of the lubricating oil flowing between the cylinder wall and piston. This results in the scuffing of the piston.

(iii) Temperatures above 250°C around the valves may cause scuffing of valve guides due to lubrication breakdown. Any further increase in temperature may cause the burning of valves and valve seats.

(iv) With the increase in the temperature of the cylinder, the tendency of the detonation increases.

(v) In SI engines pre-ignition of the charge is also possible if the engine parts are initially at high temperature.

Thus, an efficient cooling system is essential in an I.C. engine to prevent damage of the engine parts due to overheating and to maintain the performance of the engine within certain limits.

Q.37. Write down the principal parts of an I.C. engine with their functions. **(R.G.P.V., Dec. 2008)**

Ans. The principal parts of an I.C. engine are discussed below –

(i) Cylinder – Cylinder is the most important part of an I.C. engine. In this the piston moves to and fro in order to develop power. The cylinder of an engine has to withstand a high pressure and temperature. Thus the materials for cylinder should be such that it can retain adequate strength at such a high pressure and temperature. For low pressure or ordinary engines, the cylinder is made of cast iron. For high pressure or heavy duty engines, it is made of steel alloys or aluminium alloys. For multi-cylinder engines, the cylinders are cast in one block. The block is called cylinder block.

(ii) Cylinder Head – The cylinder head is fitted on one end of the cylinder. It acts as a cover to close the cylinder bore. The cylinder head consists of inlet and exhaust valves for admitting fresh charge and exhausting the burnt gases. The cylinder head contains a spark plug for igniting the fuel-air mixture.

In case of diesel engines, the cylinder head contains nozzle (i.e., fuel valve) for injecting the fuel into the cylinder.

The cylinder head is cast as one piece and bolted to one end of the cylinder. Generally, the cylinder head and cylinder block are made from the same material. To make an air tight joint, a gasket made of copper or asbestos is provided between the cylinder head and the engine cylinder.

(iii) ***Piston*** – It is also the main part of an I.C. engine. Its functions are to compress the charge during compression stroke and to transmit the force exerted by the burning of charge to the connecting rod. The pistons are generally made of aluminium alloys which are light in weight.

(iv) ***Piston Rings*** – These are circular rings and made of special steel alloys because these alloys can retain their elastic properties at high temperature. These are housed in the circumferential grooves provided on the outer surface of the piston.

There are two sets of rings mounted on the piston. The function of the lower rings is to provide effective seal to prevent leakage of the oil into the engine cylinder. Similarly, the function of the upper rings is to provide air tight seal to prevent leakage of the burnt gases into the lower portion.

(v) ***Connecting Rod*** – Its main function is to transmit force from the piston to the crankshaft. The smaller end of the connecting rod is fitted to the piston and the bigger end to the crank. The special steel alloys or aluminium alloys are used for the manufacture of connecting rods. It is subjected to alternatively tensile and compressive stresses as well as bending stresses.

(vi) ***Crankshaft*** – A crankshaft is considered as the backbone of an I.C. engine. Its function is to convert the reciprocating motion of the piston into the rotary motion with the help of connecting rod. This shaft consists of one or more eccentric portions known as cranks. The part of the crank, to which bigger end of the connecting rod is fitted, is known as crankpin. It is noted that too many main bearings create difficulty of correct alignment. A special care is required for the design and manufacture of crankshaft. Special steel alloys are used for the manufacture of crankshaft.

(vii) ***Crank Case*** – It is a cast iron case, which holds the cylinder and crankshaft of an I.C. engine and also serves as a sump for the lubricating oil.

(viii) ***Flywheel*** – It is mounted on the crankshaft. Its main function is to maintain the constant speed. It stores energy during the power stroke and release during the other strokes.

(ix) ***Cylinder Liner*** – Generally a cylinder is equipped with cylinder liner, so that, if wear and tear takes place, only the liner is damaged. This is easily replaceable as compared to the cylinder.

(x) ***Water Jacket*** – The cooling water is circulated through the water jackets surrounding the cylinder and cylinder head. The water jackets are cast integral with the cylinder.

(xi) ***Valves*** – Generally, there are two valves for every cylinder. One is the inlet valve which admits air or mixture of fuel and air in the suction stroke. The other is the exhaust valve through which the products of combustion after doing work on the piston escapes to the atmosphere.

(xii) ***Cams*** – Each valve requires a cam to open and close it at the proper point in the engine cycle. The cams are mounted on a shaft known as camshaft.

(xiii) ***Manifolds*** – The piping which connects the exhaust ports to the common exhaust system and sends the exhaust products to the muffler is called the exhaust manifold. Similarly, the piping which connects the inlet ports of the various cylinders to a common air intake for the engine is called the inlet manifold.

Q.38. Draw the neat sketch of a four-stroke petrol engine and lable various parts.

Ans. Fig. 5.16 shows a four-stroke petrol engine with name of various parts on it.

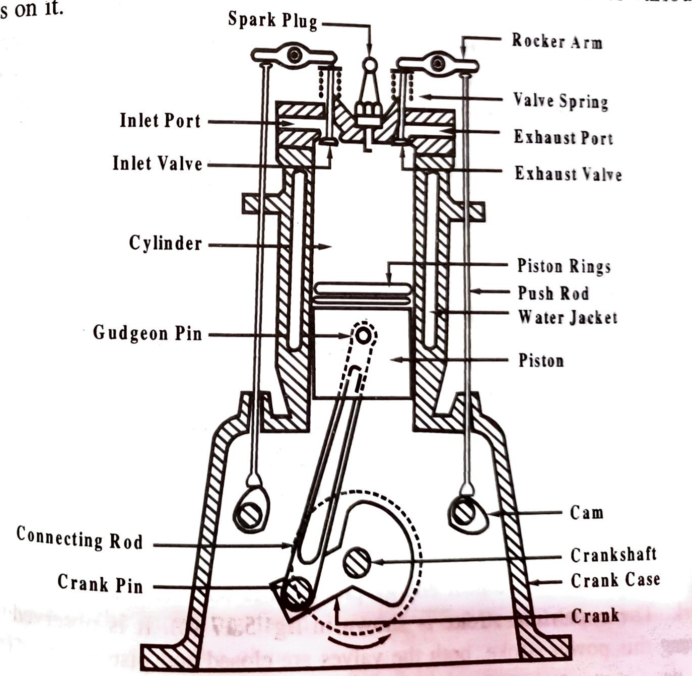


Fig. 5.16 Four-stroke Petrol Engine

Q.39. Write down working principle of 4-stroke petrol engine with neat sketches. ***(R.G.P.V., Feb. 2010)***

Or

Explain the working of a four-stroke petrol engine.
(R.G.P.V., Dec. 2008, 2010, 2011, June 2012)

Or

Write down the working of 4-stroke petrol engine with the help of neat sketches. ***(R.G.P.V., June 2009, Sept. 2009)***

Or

Discuss the working of Otto engine. ***(R.G.P.V., June 2010)***

Or

State the operation of four-stroke petrol engine. (R.G.P.V., June 2016)

Ans. In four-stroke petrol/Otto engine, the cycle of operation is completed in four strokes of the piston or two revolutions of the crankshaft. Each stroke consists of 180° of crankshaft rotation and hence a cycle consists of 720° of crankshaft rotation. The series of operations of an ideal four-stroke petrol engine is as follows –

(i) Suction stroke (ii) Compression stroke
(iii) Expansion or power stroke (iv) Exhaust stroke.

(i) Suction Stroke – Suction stroke begins when the piston is at top dead centre (T.D.C.) and starts to move downwards. At this time, the inlet valve is open and the exhaust valve is closed. As the piston moves downwards, suction is produced in the cylinder and fresh charge of fuel-air mixture enters the cylinder through the inlet valve. This stroke is shown in fig. 5.17 (a).

(ii) Compression Stroke – In compression stroke, both the inlet and exhaust valves are closed. The fresh charge is compressed due to the upward motion of the piston. As a result of compression, the temperature and pressure of the fresh charge increases considerably. This completes one revolution of the crankshaft. This stroke is shown in fig. 5.17 (b).

(iii) Expansion or Power Stroke – Shortly before the piston reaches top dead centre during compression stroke, the fresh compressed charge is ignited with the help of a spark plug. It suddenly increases the temperature and pressure of the products of combustion but the volume remains constant. Due to the increase in pressure, the piston is pushed down. The hot products of combustion expand because of high speed of the piston. During this expansion, some of the heat energy produced is converted into mechanical work. The expansion stroke is shown in fig. 5.17 (c). It is observed that during this power stroke, both the valves are closed and piston moves from top dead centre to bottom dead centre.

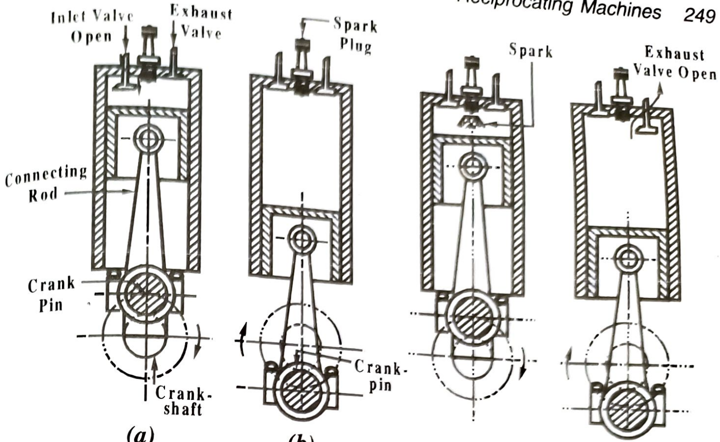


Fig. 5.17 Working of Four-stroke Petrol Engine

(iv) Exhaust Stroke – This stroke is shown in fig. 5.17 (d). In this stroke, the exhaust valve is open as piston moves from bottom dead centre to top dead centre. This movement of the piston pushes out the burnt gases from the engine cylinder and are exhausted through the exhaust valve. This completes the cycle and the engine cylinder is ready to suck the charge again.

Q.40. Explain with the help of p-v diagram the working of four-stroke petrol engine. ***(R.G.P.V., June 2015)***

Or

With the help of theoretical p-v diagram explain working of four-stroke petrol engine. ***(R.G.P.V., Dec. 2012)***

Ans. The theoretical or ideal p-v diagram of a four-stroke petrol engine is shown in fig. 5.18. In this diagram, line 1-2 represents the suction stroke.

The line 1-2 lies below the atmospheric pressure line. This pressure difference, makes the fuel-air mixture to flow into the engine cylinder. The inlet valve offers some resistance to the incoming fresh charge. That is why, the charge cannot enter suddenly into the engine cylinder. As a result of this, pressure

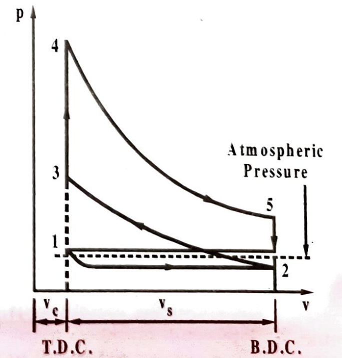


Fig. 5.18 Theoretical (or Ideal) p-v Diagram of Four-stroke Petrol Engine

inside the cylinder remains somewhat below the atmospheric pressure during suction stroke. The compression stroke is shown by the line 2-3. At the end of compression stroke, there is an increase in the pressure inside the engine cylinder. Shortly before the end of compression stroke the charge is ignited with the help of spark plug. The sparking increases temperature and pressure of the products of combustion. But the volume, practically, remains constant as shown by the line 3-4. The line 4-5 represents expansion stroke. Now the burnt gases are exhausted through the exhaust valve. Line 5-1 represents the exhaust stroke. This line lies above the atmospheric pressure line.

Q.41. Draw actual indicator diagram of a four-stroke petrol engine. Give reasons, why it is different from the ideal indicator diagram.

Ans. The actual indicator diagram of a four-stroke petrol engine is shown in fig. 5.19. It differs from the ideal indicator diagram due to following reasons –

(i) The suction of mixture in the cylinder is possible only if the pressure inside the cylinder is below atmospheric pressure.

(ii) The burnt gases can be pushed out in to the atmosphere only if the pressure of the exhaust gases is above atmospheric pressure.

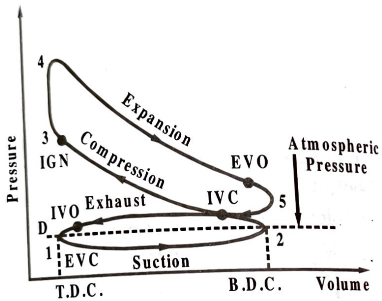


Fig. 5.19

(iii) The compression and expansion do not follow the isentropic law, as there will be heat exchange during these processes.

(iv) Sudden pressure rise is not possible after the ignition as combustion takes some time for completion and actual pressure rise is less than theoretical considered. The pressure increase takes place through some crank rotation, or increase in volume.

(v) Sudden pressure release after the opening of expansion valve is not possible and it also takes place through some crank rotation.

Q.42. Give assumptions made for working of theoretical cycle in S.I. engine.

Ans. The following assumptions were made for theoretical cycle in S.I. engine –

(i) Suction and exhaust occur at atmospheric pressure.

(ii) Suction and exhaust take place through 180° rotation of crank.

(iii) Compression and expansion also take place through 180° rotation of the crank.

(iv) Compression and expansion are isentropic.

(v) The combustion takes place instantaneously at constant volume at the end of compression stroke.

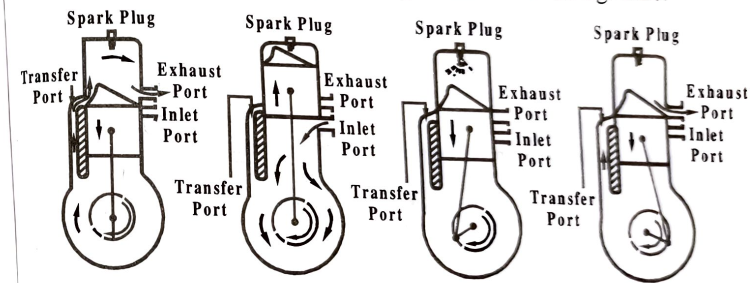
(vi) Pressure suddenly falls to the atmospheric pressure at the end of expansion stroke.

Q.43. Write down working principle of 2-stroke petrol engine with neat sketches. ***(R.G.P.V., Feb. 2010)***

Or

Explain the working of a two-stroke petrol engine. ***(R.G.P.V., Dec. 2010, June 2011)***

Ans. In a two-stroke cycle petrol engine, the suction, compression, expansion and exhuast takes place during two strokes of the piston. It means that there is one working stroke after every revolution of the crankshaft. All the four stages of a two-stroke petrol engine are shown in fig. 5.20.



(a) Suction ***(b) Compression*** ***(c) Expansion*** ***(d) Exhaust***

Fig. 5.20

(i) Suction – This process is shown in fig. 5.20 (a). In this, the piston while going down towards B.D.C., uncovers both the exhaust port and transfer port. The fresh fuel-air mixture flows into the engine cylinder from the crank case.

(ii) Compression – In this, the piston, while moving up, first closes the transfer port and then exhaust port. After that the fuel-air mixture is compressed as the piston moves upwards as shown in fig. 5.20 (b). In this process, the inlet port opens and fresh fuel-air mixture enters into the crank case.

(iii) Expansion – Shortly before the piston reaches top dead centre during compression stroke, the fuel-air mixture is ignited with the help of a spark plug. It suddenly increases the pressure and temperature of the products

of combustion. But the volume, practically remains constant. Due to rise in pressure, the piston is moved downwards. The hot burnt gases expand due to high speed of the piston. This is shown in fig. 5.20 (c). During this expansion, some of the heat energy produced is converted into mechanical work.

(iv) Exhaust – In this process, the exhaust port is opened as the piston moves downwards. The burnt gases from the engine cylinder are exhausted through the exhaust port into the atmosphere. This is shown in fig. 5.20 (d). This completes the cycle and the engine cylinder is ready to suck the charge again.

Q.44. Draw and explain the actual indicator diagram of a two-stroke petrol engine.

Ans. Actual indicator diagram for a two-stroke petrol engine is shown in fig. 5.21.

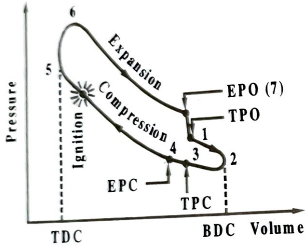


Fig. 5.21 Actual Indicator Diagram

Line 1-2-3 represents suction, i.e., from the instant transfer port opens and transfer port closes. During suction stage, the volume of fuel-air mixture and burnt gases increases. This happens as the piston moves from point 1 to point 2. In the second half of the suction process, the volume of charge and burnt gases decreases. This happens as the piston moves upwards from point 2 to point 3. A little beyond point 3 the exhaust port closes at point 4. Now the fuel-air mixture inside the engine cylinder is compressed which is shown by the line 4-5. At the end of the compression, there is an increase in the pressure inside the engine cylinder. Shortly before the end of compression the fuel-air mixture is ignited with the help of spark plug. The sparking suddenly increases pressure and temperature of the products of combustion. But the volume, practically, remains constant as shown by the line 5-6. The expansion is shown by the line 6-7. Now the exhaust port opens at point 7, and the burnt gases are exhausted through the exhaust port. It reduces the pressure. As the piston is moving towards bottom dead centre, therefore volume of burnt gases increases from point 7 to point 1, the transfer port uncovers and the suction begins.

Q.45. Write any four advantages of 4-stroke petrol engine over 2-stroke petrol engine. **(R.G.P.V., June 2014)**

Ans. Four-stroke petrol engines have following advantages over two-stroke petrol engines –

(i) Higher volumetric efficiency.

(ii) Higher thermal and part load efficiency.

(iii) Requires less cooling and lubrication.

(iv) Less wear and tear.

Q.46. Differentiate between two-stroke and four-stroke I.C. engine. **(R.G.P.V., Dec. 2011, 2014)**

Or

Differentiate between two-stroke and four-stroke engine. **(R.G.P.V., June 2010)**

Ans. **Comparison of Four-stroke and Two-stroke Engines –**

S.No.	*Four-stroke Engine*	*Two-stroke Engine*
(i)	The four-stroke engine consists of valves and valve mechanism.	Two-stroke engines have no valves but only ports.
(ii)	Volumetric efficiency more due to greater time of induction.	Lower volumetric efficiency because of lesser time for induction.
(iii)	Due to heavy weight and complication of valve mechanism, initial cost is high.	Due to light weight, simplicity and absence of valve mechanism, initial cost is less.
(iv)	The cycle is completed in four strokes of the piston or in two revolutions of the crank shaft.	The cycle is completed in two strokes of the piston or in one revolution of the crankshaft.
(v)	The turning movement is not uniform and hence heavier flywheel is needed.	More uniform turning movement and hence lighter flywheel is needed.
(vi)	For the same power the engine is heavy and bulky.	For the same power the engine is light and compact.
(vii)	Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lesser rate of wear and tear.	Because of one power stroke in one revolution greater cooling and lubrication requirement. Greater rate of wear and tear.
(viii)	Higher thermal efficiency and part load efficiency better than two-stroke engine.	Lower thermal efficiency and part load efficiency lesser than four-stroke engine.

Q.47. Why four-stroke engines have camshaft but two-stroke engines do not have ? **(R.G.P.V., Dec. 2005)**

Ans. In four-stroke engines, the intake of charge and exhaust of burnt gases is performed by means of inlet and exhaust valve respectively. The opening and closing of these valves is performed by means of camshaft. The function of the camshaft is to operate the inlet and exhaust valves through the cams, cam-followers, push rods and rocker arms. The camshaft is driven positively from the crankshaft at half the speed of the crankshaft. The cam is made of a required profile to give desired motion to the valve through the follower. The motion of the came is then transmitted to valve by means of push rod and rocker arm.

While, in two-stroke engines there are no valves for inlet of charge and for exhaust of flue gases, for these purposes there are ports. The opening and closing of these inlet, exhaust and transfer ports is performed through the reciprocating motion of piston. That is why, two-stroke engines do not have camshaft.

Q.48. Give specific applications of two-stroke petrol engine and four-stroke diesel engine.

Ans. Two-stroke petrol engines being light in weight are used in light vehicles like scooters, motor cycles, three wheelers and sprayers. However, due to their low fuel economy they are not in much use for automobiles now-a-days.

Four-stroke diesel engines are much heavier than the petrol engines, because of higher compression ratio, however they have a higher thermal efficiency. Four-stroke diesel engines are mainly used for heavy transportation vehicles, power generation, and industrial and marine applications.

Q.49. What will happen, if we supply diesel in case of petrol engines and petrol in case of diesel engines ? Explain logically. **(R.G.P.V., June 2005)**

Ans. The quality of good petrol is measured in terms of its resistance to spontaneous ignition by octane number. While, in the case of diesel, spontaneous ignition is the criteria of good quality, denoted by cetane number. Octane and cetane therefore are inverse measurements of the same property.

Good petrol engine fuels, having high octane value, have cetane value of about 10-20, and thus are difficult to autoignite, indicating their poor suitability as a diesel engine fuel. Thus, if we supply petrol in diesel engine, it will not start.

On the other hand, a good diesel engine fuel is a bad petrol engine fuel, because of its low octane number. Due to its low octane value diesel will pre-ignite and cause heavy knocking, if it is supplied in petrol engine.

Q.50. Differentiate between the spark and compression ignition engines. **(R.G.P.V., Dec. 2017)**

Or

Differentiate between S.I. and C.I. engines. **(R.G.P.V., June 2010, Dec. 2012)**

Or

Differentiate between petrol and diesel engines. **(R.G.P.V., June 2012)**

Ans. Comparison between S.I. and C.I. engines is given as follows –

S.No.	Description	S.I. Engines	C.I. Engines
(i)	Fuel	Petrol. High self ignition temperature desirable.	Diesel oil. Low self ignition temperature desirable.
(ii)	Basic cycle	Based on Otto cycle.	Based on Diesel cycle.
(iii)	Ignition	Requires an ignition system with spark plug in the combustion chamber.	Self ignition due to high temperature, casued by high compression of air, when fuel is injected.
(iv)	Introduction of fuel	Fuel and air introduced as a gaseous mixture in the suction stroke. Carburettor necessary to provide the mixture. Throttle controls the quantity of mixture introduced.	Fuel is injected directly into combustion chamber at high pressure and at the end of compression stroke. Carburettor is eliminated but a high pressure fuel pump and injector necessary. Quantity of fuel regulated in pump.
(v)	Speed	Higher maximum revolution per minute due to higher weight.	Maximum r.p.m. lower.
(vi)	Compression ratio range	6 to 10.5. Upper limit of C.R. is limited by anti-knock quality of fuel.	14 to 22. Upper limit of C.R. is limited by the rapidly increasing weight of the engine structure as the compression ratio is further increased.

(vii)	Operating pressure		
	(a) Compression pressure	7 bar to 15 bar	30 bar to 50 bar
	(b) Maximum pressure	45 bar to 60 bar	60 bar to 120 bar
(viii)	Weight per unit power	Low (0.5 to 4.5 kg/kW)	High (3.3 to 13.5 kg/kW) because of higher pressures.
(ix)	Operating cost	High	Low
(x)	Initial cost	Low	High, because of heavy weight and sturdy construction.
(xi)	Load control	Quantity governing. Throttle controls the quantity of mixture supplied.	Quality governing. The quantity of fuel is regulated by the pump, while air quantity is not controlled.
(xii)	Efficiency	Maximum efficiency is low due to low compression ratio.	Higher maximum efficiency due to higher compression ratio.

Q.51. Compare diesel engine with petrol engine with reference to maximum pressure, efficiency, power-to-weight ratio, cost and load control. Give explanation. **(R.G.P.V., Dec. 2015)**

Ans. Refer Q.50.

Q.52. Explain the working of four-stroke diesel engine with p-v diagram. **(R.G.P.V., Dec. 2016)**

Or

With the help of p-v diagram, explain the working of a four-stroke diesel engine. **(R.G.P.V., June 2013)**

Or

Explain working of 4-stroke diesel engine with the help of neat sketches. **(R.G.P.V., June 2009)**

Or

Explain the working of 4-stroke Diesel engine. **(R.G.P.V., Dec. 2014)**

Ans. Four-stroke cycle diesel engine is also known as compression ignition engine, since the ignition takes place due to the heat generated in the engine cylinder at the end of compression stroke.

Schematic diagram of a four-stroke diesel engine is shown in fig. 5.22.

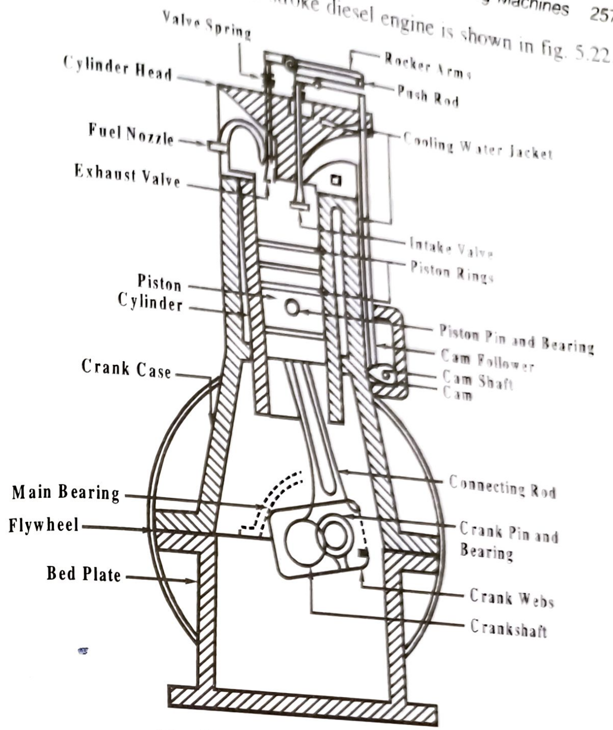


Fig. 5.22 Four-stroke Diesel Engine

All the four processes of a four-stroke diesel engine are described below –

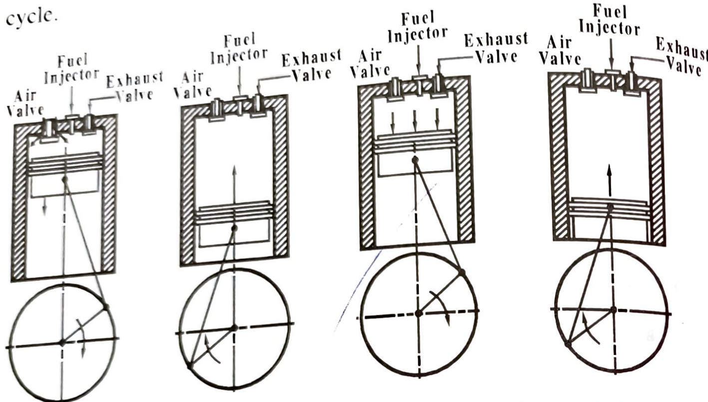
(i) Suction or Charging Stroke – This is shown in fig. 5.23 (a). In this stroke, the inlet valve opens and fresh air is sucked into the cylinder as the piston moves downward from the top dead centre. It continues till the piston reaches its bottom dead centre.

(ii) Compression Stroke – This stroke is shown in fig. 5.23 (b). In this stroke, both the valves are closed and air is compressed as the piston moves upward from bottom dead centre and reaches to top dead centre. As a result of compression, pressure and temperature of the air increases. This completes one revolution of the crankshaft.

(iii) Expansion or Working Stroke – Expansion stroke is shown in fig. 5.23 (c). In this stroke, both the valves are closed. Fuel oil is injected in the form of very fine spray into the engine cylinder just before the piston reaches the T.D.C. Fuel is ignited due to the high temperature of the air. Due

to increased pressure, the piston is pushed down with a great force and performed the mechanical work. During this expansion, piston moves from T.D.C. to B.D.C.

(iv) Exhaust Stroke – Exhaust stroke is shown in fig. 5.23 (d). In this stroke, the exhaust valve is open as the piston moves from B.D.C. to T.D.C. Products of combustion from the engine cylinder are pushed out by the piston through the exhaust valve into the atmosphere. This completes the cycle.



(a) Suction *(b) Compression* *(c) Expansion* *(d) Exhaust*

Fig. 5.23 Four-stroke Diesel Engine

The p-v diagram of the four-stroke engine is shown in fig. 5.24, Q.55, refer that.

Q.53. Compare the working of petrol and diesel engines.

(R.G.P.V., June 2013)

Ans. Refer Q.39 and Q.52.

Q.54. In what respects four-stroke diesel cycle engine differs from four-storke cycle spark engines ?

(R.G.P.V., June 2004)

Ans. Comparison between four-stroke petrol engine and four-stroke diesel engine is given as follows –

S.No.	*Four-stroke Petrol Engine*	*Four-stroke Diesel Engine*
(i)	The starting is easy due to low compression ratio.	The starting is somewhat difficult due to high compression ratio.
(ii)	These are high speed engines.	These are relatively low speed engines.

(iii)	It has compression ratio approximately from 6 to 10.	It has compression ratio approximately from 14 to 22.
(iv)	It draws a mixture of air and petrol during suction stroke.	It draws only air during suction stroke.
(v)	Overheating trouble is more due to low thermal efficiency.	Overheating trouble is less due to high thermal efficiency.
(vi)	Petrol engines are lighter and cheaper.	Diesel engines are heavier and costlier.
(vii)	Pressure at the end of compression is 10 bar.	Pressure at the end of compression is 35 bar.
(viii)	The charge is ignited with the help of spark plug.	The fuel is injected in the form of fine spray. The temperature of compressed air (about 600°C) is sufficiently high to ignite the fuel.
(ix)	The running cost of the petrol engine is high due to higher cost of petrol.	The running cost of the diesel engine is low due to lower cost of diesel.
(x)	Carburettor is used for mixing air and petrol in the required proportion and supply it to the engine during suction stroke.	The atomiser or injector is used for injecting the fuel at the end of compression stroke.
(xi)	The maintenance cost is less.	The maintenance cost is more.
(xii)	It works on Otto cycle.	It works on Diesel cycle.
(xiii)	The thermal efficiency is upto about 26%.	The thermal efficiency is upto about 40%.

Q.55. Explain working of a four-stroke diesel engine with the help of an indicator diagram.

Ans. Actual indicator diagram for a four-stroke diesel engine is shown in fig. 5.24. Line 1-2 represents the suction stroke, which lies below the atmospheric pressure line. Due to this pressure difference, the fresh air flows into the engine cylinder. The inlet valve offers some resistance to the incoming air. That is why, the air cannot enter suddenly into the engine cylinder. Dut to this reason, pressure inside the engine cylinder remains somewhat below the atmospheric

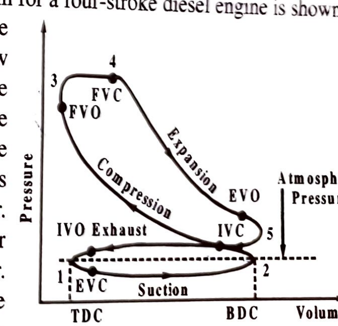


Fig. 5.24 Indicator Diagram

pressure during the suction stroke. The line 2-3 represents compression stroke. The inlet valve closes a little beyond point 2. At the end of compression stroke, there is an increase of pressure inside the engine cylinder. Shortly before the end of compression stroke, fuel valve opens and the fuel is injected into the engine cylinder. The fuel is ignited by high temperature of the compressed air.

The ignition suddenly increases temperature and volume of the products of combustion. But the pressure, practically remains constant as shown by the line 3-4. The line 4-5 represents expansion stroke. The exhaust valve opens a little before point 5. Now the burnt gases are exhausted through the exhaust valve. Line 5-1 represents the exhaust stroke, which lies above the atmospheric pressure line. Due to this pressure difference the burnt gases flows out of the engine cylinder. The exhaust valve offers some resistance to the outgoing flue gases. That is why, the flue gases cannot escape suddenly from the engine cylinder. Due to this reason, pressure inside the cylinder remains somewhat above the atmospheric pressure during the exhaust stroke.

Q.56. Define volumetric efficiency of an engine. (R.G.P.V., Dec. 2016)

Ans. Volumetric efficiency of an engine can be defined as the ratio of actual volume of charge admitted during the suction stroke at N.T.P. to the swept volume of the piston. Mathematically,

$$\eta_v = \frac{v_a}{v_s}$$

Q.57. Give expression for indicated power of an I.C. engine.

Ans. Indicated power is the power actually developed by the engine cylinder.

Let, L = Length of stroke in metres, A = Area of the piston in m^2

p_m = Actual mean effective pressure, N = Speed of the engine in r.p.m.

n = Number of working strokes per minute

= N (For two-stroke cycle engine)

= $N/2$ (For four-stroke cycle engine)

$$\text{Indicated power (I.P.)} = \frac{p_m \times 10^5 \times L \times A \times n}{60} \text{ Watts}$$

$$= \frac{100\, p_m\, LAn}{60} \text{ kW (For single cylinder engine)}$$

$$= \frac{100K\, p_m\, LAn}{60} \text{ kW (For multi-cylinder engine)}$$

where, K = Number of cylinders.

Q.58. What is brake power ? Give its expression.

Ans. Power available at the crankshaft is known as brake power.

In case of prony brake dynamometer, let

l = Length of arm in metres, N = Speed of the engine in r.p.m.

W = Brake load in newtons.

$$\text{Brake power (B.P.)} = \frac{\text{Torque in N-m} \times \text{Angle turned in radians} \times \text{r.p.m.}}{60}$$

$$= \frac{T \times 2\pi N}{60} = \frac{Wl \times 2\pi N}{60} \text{ Watts}$$

In case of rope brake dynamometer, let

S = Spring balance reading in newtons

W = Dead load in newtons

d = Diameter of the rope in metres

D_b = Diameter of brake drum in metres

N = Speed of the engine in r.p.m.

$$\text{Brake power (B.P.)} = \frac{(W - S)\,\pi DN}{60} \text{ Watts}$$

$$= \frac{(W - S)\,\pi\,(D_b + d)\,N}{60} \text{ Watts}$$

WORKING PRINCIPLE OF COMPRESSOR

Q.59. Explain the working principle of a compressor.

Ans. The function of a compressor is to compress the gases and vapours from low pressure to high. According to the second law of thermodynamics, this is only possible when the work is done on the gas by an external agency, such as prime mover, electric motors, etc, using direct and indirect transmission as shown in fig. 5.25. Thus a compressor sucks gas at low pressure (atmospheric air in case of air compressor), compresses it upto a certain pressure and delivers it at high pressure to a storage vessel called receiver (only in reciprocating compressor) from where it may be carried by a pipe line to wherever it is desired.

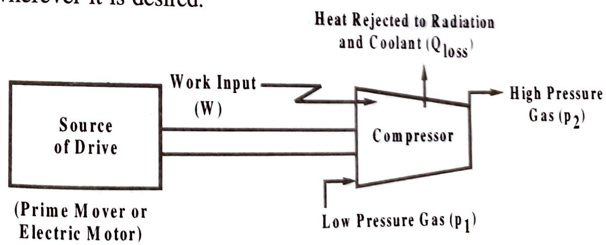


Fig. 5.25 Working Principle of a Compressor

Q.60. State the function of a compressor. State its various types. Discuss the working of any one type. ***(R.G.P.V., June 2011)***

Ans. The primary function of a compressor is to compress the air to a high pressure, which in turn can be used for various purposes. The main uses of high pressure air in industries are –

(i) To drive compressed air engines used in coal mines.

(ii) To inject fuel as spray into the cylinder of a Diesel engine.

(iii) To operate drills, hammers, air brakes for locomotives and railway carriage, water pump and paint sprays.

(iv) To start large Diesel engines.

(v) To clean workshop machines, generators, automobile vehicles etc.

(vi) To operate blast furnance, gas turbine plant, bessemer convertors used in steel plants etc.

(vii) To cool large buildings and aircrafts.

(viii) To supercharge I.C. engines.

Types of Compressor –

The compressors may be classified in following ways –

(i) According to the way of pressure developed

(a) Reciprocating compressor

(b) Rotary compressor.

Further rotary compressors are of different types –

(1) Roots blower compressor

(2) Vane blower compressor

(3) Centrifugal blower compressor

(4) Axial flow compressor.

(ii) According to the action –

(a) Single acting compressor

(b) Double acting compressor.

(iii) According to number of stages –

(a) Single stage compressor

(b) Multi-stage compressor.

Working of Centrifugal Air Compressor – A centrifugal air compressor, mainly consists of impeller and diffuser. The impeller consists of an impeller disc and impeller vanes, attached on the impeller disc radially,

forming radial diverging passages as shown in fig. 5.26. The impeller rotates with the shaft at high speed and air is drawn into the impeller eye in an axial direction. The air then flows radially outwards through the impeller passages due to centrifugal force and kinetic energy is imparted to the air with some static pressure rise.

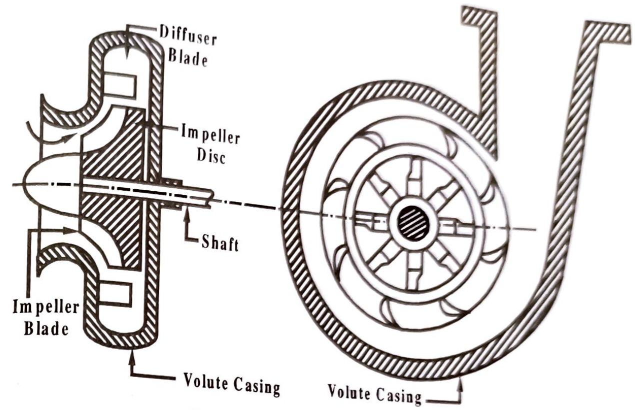


Fig. 5.26 Centrifugal Compressor

The remainder of the pressure rise is obtained in the diffuser. The diffuser which is stationary, consists of a number of fixed diverging passages. The air leaves the impeller tip with high velocity and enters the diffuser. The diffuser, in its fixed diverging passage, reduces the high velocity. Thus, by the diffusion process of air in the diffuser, kinetic energy is converted into pressure energy.

The flow from diffuser is collected in a spiral passage from which it is discharged from the compressor.

Q.61. Describe the merits and demerits of centrifugal compressors over axial flow compressors.

Ans. Following are the merits of centrifugal compressors over axial flow compressors –

(i) In centrifugal compressors low starting torque is required whereas axial flow compressors requires high axial torque.

(ii) Manufacturing and running cost of centrifugal compressors is low in comparison of axial flow compressors.

Demerits of centrifugal compressors over axial flow compressors are –

(i) Centrifugal compressors are not suitable for multi-staging whereas axial flow compressors are suitable for multi-staging.

(ii) Centrifugal compressors require large frontal area for a given rate of flow whereas axial flow compressors require less frontal area for a given rate of flow. Thus suitable for aircrafts.

Q.62. Distinguish between positive displacement and non-positive displacement compressor. ***(R.G.P.V., Dec. 2015)***

Ans. Air compressors may be broadly classified into following two types –

(i) Positive displacement compressors

(ii) Non-positive or dynamic displacement compressors.

In positive displacement type compressors, a given quantity of air or gas is trapped in compression chamber and the volume it occupies is reduced mechanically. This rises the pressure of air at discharge. With the variation in discharge pressure, the air flow remains constant at a given speed.

In non-positive or dynamic compressors, the impellers rotating at very high speeds, impart kinetic energy to continuously flowing air or gas. This kinetic energy is then changed into pressure energy both by the impellers and the discharge volutes or diffusers.

●●●

RGPV

B.E. (First Semester) EXAMINATION, Dec., 2010
(Grading System)
(Common for all Branches)
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : Attempt any *five* questions. Internal choice is given. Draw figures and charts to support your answer. Use of Steam table is permitted. All questions carry equal marks.

1. (a) Discuss the effect of carbon, silicon, phosphorus on the behaviour of cast iron. (See Unit-I, Page 8, Q.11)

(b) Draw stress-strain diagram for mild steel, clearly showing various points. (See Unit-I, Page 32, Q.53)

Or

2. (a) What are the composition, properties and uses of high speed steel ? State its various types. (See Unit-I, Page 21, Q.29)

(b) Draw a neat sketch of iron-carbon equilibrium diagram and explain various reactions involved. (See Unit-I, Page 1, Q.21)

3. (a) Draw a simple diagram of lathe machine and discuss any *five* operations, that can be performed on it. (See Unit-II, Page 98, Q.89)

(b) Discuss the measurement by vernier caliper with neat sketch. (See Unit-II, Page 67, Q.41)

Or

4. (a) Draw a neat sketch of radial drilling machine, discuss its various operations. (See Unit-II, Page 104, Q.97)

(b) Define the following measurement terms :
(i) Accuracy (ii) Sensitivity (iii) Precision (iv) Hysteresis (v) Error (See Unit-II, Page 48, Q.19)

5. (a) State and prove Bernoulli's equation for incompressible fluids. State its assumptions. (See Unit-III, Page 115, Q.21)

(b) Draw a neat sketch of hydraulic power plant. State the function of any *five* important components. **

Or

6. (a) Discuss the working of fluid coupling and state its applications. (See Unit-III, Page 121, Q.25)

(b) Describe the construction and working of Pelton turbine. (See Unit-III, Page 131, Q.38)

7. (a) Draw a neat sketch of a Cochran boiler. State the function of any

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

five important parts. (See Unit-IV, Page 165, Q.27)

(b) Using steam tables, determine the mean specific heat for superheated steam at 1 bar between temperatures of 150°C and 200°C. (See Unit-IV, Page 197, Prob.18)

Or

8. (a) Calculate the equivalent evaporation of boiler per kg of coal fired, if the boiler produces 50000 kg of wet steam per hour with a dryness fraction of 0.95 and operating at 10 bar. The coal burnt per hour in furnace is 5500 kg and feed water temperature is 40°C. (See Unit-IV, Page 176, Prob.8)

(b) Define Refrigeration. Draw a layout of vapor absorption refrigeration system. State the function of each component. **

9. (a) Explain the working of two stroke petrol engine. (See Unit-V, Page 251, Q.43)

(b) Draw a neat sketch of steam engine. State the function of any *five* important components. (See Unit-V, Page 206, Q.7)

Or

10. (a) Explain the working of four-stroke petrol engine. (See Unit-V, Page 248, Q.39)

(b) Differentiate between an Otto cycle and a Diesel cycle. (See Unit-V, Page 225, Q.27)

RGPV

B.E. (First/Second Semester) EXAMINATION, June, 2011 (Common for all Branches) BASIC MECHANICAL ENGINEERING [BE–203(GS)]

Note : Attempt any *five* questions. Use of Steam table is permitted. Support your answer with figures, charts, etc. All questions carry equal marks.

1. (a) Sketch stress-strain diagram for M.S. and cast iron. Discuss various points for M.S. (See Unit-I, Page 34, Q.54)

(b) Discuss the effect of alloying elements on the properties of cast iron. (See Unit-I, Page 8, Q.11)

Or

2. (a) Describe the various mechanical properties of materials in short. (See Unit-I, Page 28, Q.44)

(b) Define Steel. Discuss its various types, uses and their applications. (See Unit-I, Page 24, Q.33)

3. (a) Discuss any *three* operations that can be performed on a radial drilling

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

machine. Also draw a labelled diagram of a radial drilling machine. (See Unit-II, Page 104, Q.97)

(b) Explain the following properties of any measuring instrument :
(i) Hysteresis (ii) Sensitivity (iii) Accuracy and precision
(iv) Errors (v) Response time (See Unit-II, Page 46, Q.8)

Or

4. (a) What is the use of sine bar ? State the process to measure any angle using sine bar with neat sketch. (See Unit-II, Page 76, Q.56)

(b) Draw a neat labelled diagram of shaper machine. Also state the operations performed on it. **

5. (a) Describe the construction and working of any *one* hydraulic turbine. (See Unit-III, Page 131, Q.38)

(b) What do you understand by fluid coupling ? Explain its working. State its uses. (See Unit-III, Page 121, Q.25)

Or

6. (a) State the function of a compressor. State its various types. Discuss the working of any *one* type. (See Unit-V, Page 262, Q.60)

(b) Discuss in short any *three* of the following properties related to fluids :
(i) Viscous flow (ii) Laminar flow (iii) Turbulent flow
(iv) Pressure, viscosity, density **

7. (a) Differentiate between vapour absorption system and vapour compression system. (See Unit-III, Page 108, Q.9)

(b) Calculate the equivalent evaporation from and at 100°C for a boiler, which receives water at 60°C and produces steam at 1.5 MPa and 300°C. The steam generation rate is 16000 kg/hr. Coal is burnt at the rate of 1800 kg/hr. The calorific value of coal is 34750 kJ/kg. Also calculate the thermal efficiency of boiler. (See Unit-IV, Page 180, Prob.14)

Or

8. (a) Discuss Eco-friendly refrigerants. State their properties. Why are they more important in present time ? **

(b) A chimney of 30 m height is discharging hot gases at 320°C, when outside temperature is 30°C. The air-fuel ratio is 20. Calculate :
(i) The draught produced in mm of water column.
(ii) The temperature of gases for maximum discharge in a given time and what would be the draught produced corresponding. (See Unit-IV, Page 187, Prob.15)

9. (a) Discuss the working principle and functions of each part of steam engine. (See Unit-V, Page 205, Q.6)

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

(b) Discuss the working of two-stroke petrol engine
(See Unit-V, Page 251, Q.43)

Or

10. (a) Explain Otto cycle and derive an expression for efficiency of Otto cycle.
(See Unit-V, Page 222, Q.25)

(b) In an engine working on ideal Otto cycle, the temperature at the beginning and at the end of compression are 27°C and 327°C. Find the compression ratio and air standard efficiency of the engine.
(See Unit-V, Page 231, Prob.7)

RGPV

B.E. (First/Second Semester) EXAMINATION, Dec., 2011 (Common for all Branches) BASIC MECHANICAL ENGINEERING [BE–203(GS)]

Note : Attempt *five* questions in all selecting *one* question from each Unit. Use of Steam table is permitted. Assume suitable missing data, if any.

Unit-I

1. (a) Define the following mechanical properties of engineering material : 6
(i) Ductility (ii) Brittleness (iii) Toughness
(See Unit-I, Page 26, Q.39)

(b) Discuss the iron-carbon diagram and various allotropies of steel. 8
(See Unit-I, Page 13, Q.21)

Or

2. (a) What is cast iron ? What are different types of cast iron ? Discuss their properties. (See Unit-I, Page 7, Q.10) 8

(b) Define hardness. Explain any hardness testing method in brief. 6
(See Unit-I, Page 36, Q.56)

Unit-II

3. (a) Explain the term measurement and measurement error. 6
(See Unit-II, Page 43, Q.5)

(b) What is a sine bar ? Explain its use with the help of neat diagram and explain. (See Unit-II, Page 78, Q.60) 8

Or

4. Explain the working of a vertical drilling machine with the help of a neat sketch. Also state the parameters used to specify a drilling machine. 14
(See Unit-II, Page 100, Q.94)

Unit-III

5. Write a short note on hydraulic turbine and fluid coupling explaining their working with the help of neat sketches. (See Unit-III, Page 132, Q.40) 14

Or

6. (a) Differentiate between Laminar and Turbulent flow. ** 6
(b) State Newton's law of viscosity. The velocity distribution of flow over a flat plate is given by $u = \frac{1}{3}y^2 - \frac{1}{4}y$, where u is the velocity of water in m/sec at a distance y m above the plate. Determine the shear stress at a distance 1.8 m above the plate. 8
(See Unit-III, Page 110, 109, Q.11, Prob.2)

Unit-IV

7. (a) Differentiate between the following : 9
(i) Boiler mounting and accessory (See Unit-IV, Page 170, Q.32)
(ii) Natural draught and forced draught (See Unit-IV, Page 184, Q.48)
(iii) Vapour compression and vapour absorption refrigeration system **

(b) What is eco-friendly refrigerant ? Name any refrigerant and its properties. ** 5

Or

8. (a) What is second law of thermodynamics ? Explain the *two* statements of this law. (See Unit-IV, Page 143, Q.13) 8
(b) Define boiler efficiency (See Unit-IV, Page 174, Q.40)
and C.O.P. of a refrigeration system. ** 6

Unit-V

9. (a) What is a steam engine ? Give its classification. 6
(See Unit-V, Page 203, Q.2)

(b) Dry saturated steam at 10 bar is admitted into the cylinder of a double acting, single cylinder steam engine. The cylinder diameter is 275 mm and stroke 650 mm. Cut-off occurs at 50% of the stroke length and pressure is 1.5 bar. Assuming a diagram factor of 0.75, find the indicated power of the engine, if it runs at 380 r.p.m. 8
(See Unit-V, Page 214, Prob.1)

Or

10. (a) Differentiate between two-stroke and four-stroke I.C. engine. 6
(See Unit-V, Page 253, Q.46)

(b) Explain the working of four-stroke petrol engine. 8
(See Unit-V, Page 248, Q.39)

Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

RGPV

EXAMINATION, June, 2012
(Grading System)
(Common for all Branches)
BASIC MECHANICAL ENGINEERING [BE–203(GS)]

Note : Attempt *five* questions in all selecting *one* question from each Unit. All questions carry equal marks.

Unit-I

1. (a) Define the following mechanical properties of engineering material –
(i) Ductility (ii) Hardness (iii) Toughness (iv) Machinability
(See Unit-I, Page 28, Q.42)

(b) Discuss the stress-strain curve for a ductile material.
(See Unit-I, Page 32, Q.53)

Or

2. (a) What is alloy steel ? Name two types of alloy steel giving their composition and uses.
(See Unit-I, Page 20, Q.27)

(b) Define hardness and explain the testing procedure for determining hardness of engineering material.
(See Unit-I, Page 36, Q.56)

Unit-II

3. Explain the construction and uses of the following measuring instruments–
(i) Dial gauge (ii) Micrometer
(See Unit-II, Page 73, Q.50)

Or

4. (a) Describe the measurement of flow rate of a fluid flowing through a circular pipe.
(See Unit-II, Page 57, Q.27)

(b) Name and explain five operations which can be performed on a lathe machine.
(See Unit-II, Page 98, Q.88)

Unit-III

5. (a) State Newton's law of viscosity. What is the effect of temperature on viscosity of water and gas ?
(See Unit-III, Page 111, Q.12)

(b) What is fluid coupling ? Explain its working principle.
(See Unit-III, Page 121, Q.25)

Or

6. (a) Differentiate between absolute pressure and gauge pressure. How can we measure pressure exerted by fluid ?
(See Unit-III, Page 106, Q.5)

(b) Differentiate between the following – **
(i) Laminar and turbulent flow
(ii) Turbine and compressor
(See Unit-III, Page 128, Q.34)

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

Unit-IV

7. (a) State and explain first law of thermodynamics.
(See Unit-IV, Page 141, Q.11)

(b) Explain the working of a simple vapour compression refrigeration cycle. **

Or

8. (a) Define the following terms –
(i) Sensible heat of water (ii) Latent heat of steam
(iii) Dryness fraction of steam (iv) Saturation temperature of steam
(See Unit-IV, Page 188, Q.54)

(b) Explain the working of a water tube boiler with the help of a neat sketch.
(See Unit-IV, Page 168, Q.30)

Unit-V

9. (a) Explain the working of a double acting steam engine with the help of a neat diagram.
(See Unit-V, Page 203, Q.3)

(b) Differentiate between petrol and diesel engine.
(See Unit-V, Page 255, Q.50)

Or

10. (a) A reversible heat engine delivers 0.6 kW power and rejects heat energy to a reservoir at 300 K at the rate of 24 kJ/min. Determine the cycle efficiency and temperature of the thermal reservoir supplying heat to the engine.
(See Unit-V, Page 230, Prob.5)

(b) Explain the working of a 4-stroke petrol engine.
(See Unit-V, Page 248, Q.39)

RGPV

B.E. (First/Second Semester)
EXAMINATION, Dec., 2012
(Grading System)
(Common for all Branches)
BASIC MECHANICAL ENGINEERING [BE–203]

Note : Solve one question from each unit.

Unit-I

1. (a) Draw the stress-strain curve for a ductile metal and point out its salient features. 7
(See Unit-I, Page 32, Q.53)

(b) Explain the following reactions in relation to iron-carbon equilibrium diagram – 7
(i) Eutectic reaction (ii) Eutectoid reaction (iii) Peritectic reaction
(See Unit-I, Page 17, Q.22)

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

Or

2. (a) Give the broad classification of engineering materials. 7
(See Unit-I, Page 3, Q.2)

(b) Define the following mechanical properties of an engineering material –
(i) Hardness (ii) Toughness (iii) Fatigue. 7
(See Unit-I, Page 27, Q.41)

Unit-II

3. (a) Explain the construction and use of a combination set. 7
(See Unit-II, Page 79, Q.63)

(b) Discuss the different sources of errors in the act of taking measurement. (See Unit-II, Page 43, Q.6) 7

Or

4. (a) Sketch a micrometer and explain its working. 7
(See Unit-II, Page 69, Q.45)

(b) Explain the construction and working principle of a lathe machine with neat sketch. (See Unit-II, Page 96, Q.86) 7

Unit-III

5. (a) Establish the Bernoulli's theorem from the Euler equation of motion through a stream tube. (See Unit-III, Page 115, Q.20)

(b) Enumerate important characteristics of ** 7
(i) Laminar flow (ii) Turbulent flow.

Or

6. (a) Explain working principle of fluid coupling. 7
(See Unit-III, Page 121, Q.25)

(b) A pipe 300 meters long has a slope of 1 in 100 and tapers from 1 m diameter at the high end to 0.5 m at the low end. Quality of water flow is 5400 litres per minute. If the pressure at the high end is 70 kPa, find the pressure at the low end. 7
(See Unit-III, Page 121, Prob.6)

Unit-IV

7. (a) Explain with neat sketch vapour compression refrigeration system also draw p-v and T-s diagrams. ** 7

(b) Find enthalpy of steam at 10 bar in following conditions – 7
(i) Dry and saturated
(ii) Wet having dryness fraction 0.95
(iii) Superheated to a degree of superheat = 50°C.
(See Unit-IV, Page 197, Prob.16)

Or

8. (a) Give classification of boilers on different basis. 7
(See Unit-IV, Page 161, Q.23)

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

(b) A coal fired boiler plant consumes 400 kg of coal per hour. The boiler evaporates 3200 kg of water at 44.5°C into superheated steam at a pressure of 12 bar and 274.5°C. If the calorific value of fuel is 32,760 kJ/kg of coal, determine
(i) Equivalent evaporation
(ii) Thermal efficiency of boiler. 7
(See Unit-IV, Page 179, Prob.13)

Unit-V

9. (a) With the help of theoretical p-v diagram explain working of four-stroke petrol engine. (See Unit-V, Page 249, Q.40) 7

(b) Explain Carnot cycle and find expression for efficiency. 7
(See Unit-V, Page 219, Q.23)

Or

10. (a) With the help of theoretical p-v diagram explain working of single acting steam engine. 7

(b) Differentiate between SI and CI engines. (See Unit-V, Page 255, Q.50) 7

RGPV

B.E. (First/Second Semester)

EXAMINATION, June, 2013
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : Attempt five questions selecting one from each unit. All questions carry equal marks.

Unit-I

1. (a) Explain the stress-strain diagram of mild steel with the help of a neat sketch. (See Unit-I, Page 32, Q.53)

(b) Define following properties of engineering materials –
(i) Hardness (ii) Ductility (iii) Fatigue (iv) Modulus of elasticity
(See Unit-I, Page 32, Q.51)

Or

2. (a) Describe composition of grey cast iron and its properties and application in engineering field. (See Unit-I, Page 6, Q.7)

(b) What are alloy steels ? Why alloying is done ? Explain.
(See Unit-I, Page 18, Q.23)

Unit-II

3. (a) What is the use of micrometer ? Explain its working.
(See Unit-II, Page 69, Q.45)

(b) Explain the uses of sine bar. (See Unit-II, Page 78, Q.59)

Or

4. (a) Write short note on slip gauges. (See Unit-II, Page 74, Q.52)

(b) With the help of a simple sketch, explain different components of

lathe machine. (See Unit-II, Page 93, Q.85)

Unit-III

5. (a) What is Bernoulli's theorem for incompressible fluid ? How is it used to measure flow in a pipe ? (See Unit-III, Page 115, Q.21)
   (b) How hydraulic pumps are classified ? Explain. (See Unit-III, Page 123, Q.27)

Or

6. (a) Differentiate between viscous and non-viscous flow. **
   (b) Explain the working of a fluid coupling. (See Unit-III, Page 121, Q.25)

Unit-IV

7. (a) State and explain second law of thermodynamics. (See Unit-IV, Page 143, Q.13)
   (b) Explain the working of a vapour compression refrigeration system with the help of a neat diagram. **

Or

8. Steam at 18 bar and dryness friction 0.9 is heated at constant pressure until it becomes dry and saturated. Find the increase in volume, heat supplied and work done per kg of steam. Further if volume of steam is kept constant, find how much heat be extracted to reduce the pressure of steam to 14 bar. (See Unit-IV, Page 201, Prob.22)

Unit-V

9. (a) What is steam engine ? Explain its actual working with the help of actual indicator diagram. (See Unit-V, Page 210, Q.14)
   (b) Compare the working of petrol and diesel engines. (See Unit-V, Page 258, Q.53)

Or

10. (a) With the help of p-v diagram explain the working of a four-stroke diesel engine. (See Unit-V, Page 256, Q.52)
    (b) An engine working on Otto cycle is supplied with air at 0.1 MPa and 35°C. The compression ratio is 8. Heat supplied is 2100 kJ/kg. Calculate the maximum pressure and temperature of the cycle, cycle efficiency and mean effective pressure. (See Unit-V, Page 234, Prob.10)

RGPV

B.E. (First/Second Semester) EXAMINATION, Dec., 2013 BASIC MECHANICAL ENGINEERING (BE–203)

Note : (1) Attempt all questions. All questions carry equal marks.
(2) Use of steam tables and Mollier chart's is permitted without written any thing by Pen or Pencil.

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

1. Give classification of engineering materials. Give applications of cast iron and carbon steels (at least-5). Plot stress strain curve for Cast iron. Distinguish between stress-strain curve and true stress-strain curve. (See Unit-I, Page 35, Q.55)

Or

How does a stress-strain curve of a brittle material differs from a ductile material ? Explain with the help of a plot. On which machine the tensile test of a material is performed ? What is the object of performing Fatigue test on a material ? (See Unit-I, Page 39, Q.61)

2. With the help of a neat sketch explain the working of a combination set, mentioning it uses. Also give a neat sketch of a sine bar set up for measuring an angle of a workpiece. (See Unit-II, Page 81, Q.64)

Or

Give types of lathe. Name the various operations which can be performed on a lathe machine. What are the advantages of using a taper turning Attachement ? (See Unit-II, Page 98, Q.90)

3. Define the terms –
   (a) Viscosity (b) Pressure (c) Kinetic energy
   (d) Datum energy (e) Compressible fluid.
   (See Unit-III, Page 113, Q.16)

Or

Define pump, compressor, turbine, positive displacement machine and pneumatic Machine. (See Unit-III, Page 134, Q.43)

4. State the differences between the following boilers –
   (a) Stationary and portable boiler
   (b) Forced circulation and natural circulation boiler
   (c) Externally and internally fired boiler
   (d) Single tube and multi tube boiler.
   (See Unit-IV, Page 163, Q.24)

Or

With the help of a neat sketch, explain the working of a Babcock and Wilcox Boiler. (See Unit-IV, Page 167, Q.29)

5. Define the term diagram factor, as applied to a steam engine. Also define the term indicator diagram and explain how it is obtained ? (See Unit-V, Page 207, Q.8)

Or

Define the following terms as applied to a steam engine.
(a) Clearance (b) Swept volume (c) Mean piston speed
(d) Dead centres (e) Crank throw (f) Piston stroke
(g) Cylinder bore. (See Unit-V, Page 208, Q.12)

RGPV

B.E. (First/Second Semester)
EXAMINATION, June, 2014
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D part has internal choice.
(ii) All parts of each question are to be attempted at one place.
(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.
(iv) Except numericals, Derivation, Design and Drawing etc.
(v) Use of steam table is permitted.

1. (a) Explain the difference between malleability and ductility. **(See Unit-I, Page 25, Q.37)**
(b) Explain the stress-strain diagram for mild steel. **(See Unit-I, Page 32, Q.53)**
(c) Give the classification of carbon steel. **(See Unit-I, Page 10, Q.15)**
(d) Explain the steel and iron carbon diagram. **(See Unit-I, Page 13, Q.21)**

Or

(e) A rod 150 cm long and diameter 2 cm is subjected to an axial pull of 20 kN. If the modulus of elasticity of the material of the rod is 2×10^5 N/mm^2, determine stress, strain, and the elongation of the rod. **(See Unit-I, Page 36, Prob.1)**

2. (a) Briefly explain the devices used for measuring the pressure of a fluid. **(See Unit-II, Page 53, Q.21)**
(b) Explain the principle of temperature measurement. **(See Unit-II, Page 50, Q.14)**
(c) Describe vernier caliper with neat sketch. **(See Unit-II, Page 66, Q.40)**
(d) Explain the construction and working principle of a simple lathe machine. **(See Unit-II, Page 96, Q.86)**

Or

(e) Explain the principle of venturimeter with a neat sketch and derive the expression for the rate of flow of fluid through it. **(See Unit-II, Page 57, Q.27)**

3. (a) What do you mean by vacuum pressure ? **(See Unit-III, Page 106, Q.4)**
(b) State the Newton's law of viscosity and give examples of its application. **(See Unit-III, Page 110, Q.11)**
(c) What factors decide whether Kaplan, Francis or a Pelton type turbine would be used in a hydroelectric project ? **

****Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus**

(d) State Bernoulli's theorem and derive equation for the flow of an incompressible fluid. Mention the assumptions made for deriving it. **(See Unit-III, Page 115, Q.21)**

Or

(e) Calculate specific weight, density, specific volume and specific gravity of petrol, if one litre of petrol weight 6.867 N. **(See Unit-III, Page 109, Prob.1)**

4. (a) State and explain second law of thermodynamics. **(See Unit-IV, Page 143, Q.13)**
(b) Show the various processes of steam in a T-S diagram. **(See Unit-IV, Page 196, Q.66)**
(c) How boilers are classified ? Write down few names of mountings and accessories of a boiler. **(See Unit-IV, Page 169, Q.31)**
(d) Calculate the internal energy of 1 kg of steam at a pressure of 10 bar, when the steam is
(i) 0.9 dry (ii) dry saturated (iii) super heated to 250°C **(See Unit-IV, Page 198, Prob.19)**
(e) The following observations were made in a boiler
Coal used = 200 kg/hr Mass of steam = 2000 kg/hr
Steam pressure = 11.2 bar Dryness fraction = 0.95
Feed water temperature = 32.15°C
Calorific value of coal = 28800 kJ/kg
Calculate the equivalent evaporation from and at 100°C per kg of coal and boiler efficiency. **(See Unit-IV, Page 178, Prob.11)**

5. (a) What is Carnot cycle and its importance ? **(See Unit-V, Page 218, Q.20)**
(b) Write any four advantages of 4 stroke petrol engine over 2 stroke petrol engine. **(See Unit-V, Page 253, Q.45)**
(c) For the same compression ratio and heat supplied, state the order of decreasing air standard efficiency of Otto, Diesel and Dual cycle. **(See Unit-V, Page 229, Q.31)**
(d) Find the power output of a Diesel engine working on a diesel cycle with compression ratio of 16 and air flow rate of 0.25 kg/sec. the initial condition of air at 1 bar absolute and 27°C temperature, heat added per cycle 2500 kJ/kg. **(See Unit-V, Page 238, Prob.12)**

Or

(e) The minimum pressure and temperature in a Otto cycle are 100 kPa and 27°C. The amount of heat added to the air per cycle is 1500 kJ/kg. Determine the pressures and temperatures at all points of the air standard Otto cycle. Also calculate the specific work and thermal efficiency of the cycle for compression ratio of 8 : 1. **(See Unit-V, Page 233, Prob.9)**

RGPV

B.E. (First/Second Semester)
EXAMINATION, Dec., 2014
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D part has internal choice.
(ii) All parts of each question are to be attempted at one place.
(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.
(iv) Except numericals, Derivation, Design and Drawing etc.

1. (a) Define tensile strength of a material. **(See Unit-I, Page 31, Q.47)**
(b) State the composition of grey cast Iron and it's applications. **(See Unit-I, Page 6, Q.6)**
(c) What is modulus of elasticity ? Give it's unit of measurement. **(See Unit-I, Page 31, Q.49)**
(d) Explain the iron-carbon diagram. **(See Unit-I, Page 13, Q.21)**
Or
Define hardness and explain the brinell hardness test. **(See Unit-I, Page 36, Q.56)**

2. (a) Define temperature and name one device and it's operating principle for measuring temperature. **(See Unit-II, Page 49, Q.12)**
(b) What is orifice meter ? Draw its diagram and give the formula used for measurement. **(See Unit-II, Page 59, Q.28)**
(c) Explain the operating procedure of vernier caliper. **(See Unit-II, Page 67, Q.41)**
(d) Write a short note on (i) Combination set (ii) Sine bar **(See Unit-II, Page 81, Q.65)**
Or
Explain the quick return mechanism used in shaper with neat sketch. **

3. (a) Differentiate between real fluid and ideal fluid. **(See Unit-III, Page 110, Q.10)**
(b) Define kinematic viscosity of fluid. What is it's unit of measurement ? **(See Unit-III, Page 108, Q.8)**
(c) What is hydrostatic law ? Explain it. **(See Unit-III, Page 112, Q.14)**
(d) What is venturimeter ? Derive the expression for measuring rate of flow of fluid in a horizontal pipe. **(See Unit-II, Page 57, Q.27)**
Or
What is a hydraulic turbine ? Draw a neat sketch of pelton turbine

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

and explain it's working. **(See Unit-III, Page 132, Q.39)**

4. (a) What is internal energy ? **(See Unit-IV, Page 190, Q.58)**
(b) Name boiler mountings and explain one of them. **(See Unit-IV, Page 171, Q.34)**
(c) At 1.2 MPa, 250°C steam enters into a turbine and expands to 30°C. Determine the work output of turbine for 10 kg/s of flow rate. **(See Unit-IV, Page 200, Prob.21)**
(d) Explain the operating principle of a vapour compression refrigeration cycle. **
Or
In a boiler trial the following observation are made
Feed water temperature = 40°C
Boiler pressure = 15 bar
Dryness fraction of steam = 0.85
Coal consumption = 450 kg/hr
Feed water supplied = 3500 kg/hr
C.V. of coal = 40,000 kJ/kg
Calculate the evaporation factor and equivalent evaporation at 100°C in kg/kg of coal. **(See Unit-IV, Page 176, Prob.9)**

5. (a) Draw the hypothetical indicator diagram of a steam engine. **(See Unit-V, Page 209, Q.13)**
(b) Draw the p-v diagram of Carnot cycle and express it's efficiency. **(See Unit-V, Page 219, Q.21)**
(c) Explain the fundamental difference between Otto and Diesel cycle. **(See Unit-V, Page 225, Q.27)**
(d) Explain the working of a 4 stroke diesel engine. **(See Unit-V, Page 256, Q.52)**
Or
Differentiate between two stroke and four stroke I.C. engine. **(See Unit-V, Page 253, Q.46)**

RGPV

B.E. (First/Second Semester)
EXAMINATION, June 2015
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D part has internal choice.
(ii) All parts of each questions are to be attempted at one place.
(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

marks, part D (Max. 400 words) carry 7 marks.

(iv) Except numericals, Derivation, Design and Drawing etc.

Unit-I

1. (a) Define stress and strain. (See Unit-I, Page 25, Q.35)

(b) State the effects of adding the alloying elements such as manganese and tungsten to steels. (See Unit-I, Page 18, Q.25)

(c) State and explain Hooke's law and modulus of elasticity. (See Unit-I, Page 31, Q.48)

(d) Draw and explain stress-strain diagram for an elastic material. (See Unit-I, Page 32, Q.53)

Or

Write down composition of carbon steel and enlist mechanical properties. (See Unit-I, Page 12, Q.19)

Unit-II

2. (a) Write down the principle of temperature measurement. (See Unit-II, Page 50, Q.14)

(b) Explain the term threshold value of any measuring instrument. (See Unit-II, Page 48, Q.10)

(c) What are the various sources of measuring errors ? (See Unit-II, Page 43, Q.6)

(d) Give the labelled diagram, method of use and application of sine bar. (See Unit-II, Page 78, Q.68)

Or

Explain various lathe operations in brief. (See Unit-II, Page 96, Q.87)

Unit-III

3. (a) State Newton's law of viscosity. (See Unit-III, Page 110, Q.11)

(b) What are the applications of Bernoulli's theorem ? (See Unit-III, Page 115, Q.19)

(c) How fluids are classified ? (See Unit-III, Page 110, Q.10)

(d) Derive Bernoulli's equation for a perfect incompressible liquid. (See Unit-III, Page 118, Q.22)

Or

Explain construction and working of fluid coupling. (See Unit-III, Page 122, Q.25)

Unit-IV

4. (a) Write down two statements of second law of thermodynamics. (See Unit-IV, Page 146, Q.14)

(b) What is equivalent evaporation ? (See Unit-IV, Page 175, Q.41)

(c) Find the enthalpy of steam at 9 bar, when it is dry saturated. (See Unit-IV, Page 197, Prob.17)

(d) Explain with neat sketches, the working of vapour compression system. Also draw P-V and T-S diagrams. **

Or

5000 kg of steam is produced per hour at a pressure of 7 bar in a boiler. The temperature of feed water is 40°C. The dryness fraction of steam at exit is 0.98. The mass of coal burnt per hour is 700 kg and calorific value of coal is 31000 kJ/kg.

Determine the equivalent evaporation and boiler efficiency. (See Unit-IV, Page 177, Prob.10)

Unit-V

5. (a) Give list of parts of double acting steam engine. (See Unit-V, Page 204, Q.4)

(b) What is the function of connecting rod in heat engines ? (See Unit-V, Page 205, Q.5)

(c) Why cooling of an I.C. engine is required ? (See Unit-V, Page 245, Q.36)

(d) Explain with the help of p-v diagram the working of four-stroke petrol engine. (See Unit-V, Page 249, Q.40)

Or

Explain carnot cycle and find expression for ideal efficiency of Carnot engine. (See Unit-V, Page 219, Q.23)

RGPV

B.E. (First/Second Semester)
EXAMINATION, Dec. 2015
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D part has internal choice.

(ii) All parts of each question are to be attempted at one place.

(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.

(iv) Except numericals, Derivation, Design and Drawing etc.

1. (a) State the material used for making of the following parts, stating reason – twist drill, milling cutter. (See Unit-I, Page 30, Q.22)

(b) Compare properties of ferrous and non-ferrous metals. (See Unit-I, Page 4, Q.3)

(c) Define the following properties of material – ductility, toughness, Hardness, Creep. (See Unit-1, Page 28, Q-43)

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

(d) Sketch the iron-carbon equilibrium diagram and point out its salient features. (See Unit-I, Page 13, Q.21)

Or

What is the purpose of testing engineering materials ? (See Unit-I, Page 30, Q.45)

Explain the following reactions in relation to iron-carbon equilibrium diagram –
(i) Eutectic reaction
(ii) Eutectoid reaction
(iii) Peritectic reaction. (See Unit-I, Page 17, Q.22)

2. (a) Distinguish between –
(i) Range and span
(ii) Error and accuracy
(iii) Accuracy and precision (See Unit-II, Page 48, Q.11)

(b) Explain how sine bar used for setting an angle and for finding an unknown angle. (See Unit-II, Page 77, Q.58)

(c) Describe the construction and use of dial gauge. (See Unit-II, Page 72, Q.49)

(d) Explain the principle of operation of rotameter for discharge measurement. (See Unit-II, Page 56, Q.26)

Or

Describe with a neat sketch, the working of a bimetallic thermometer. (See Unit-II, Page 50, Q.15)

3. (a) Distinguish between inward and outward flow reaction turbine. (See Unit-III, Page 130, Q.37)

(b) Distinguish between positive displacement and non-positive displacement compressor. (See Unit-V, Page 264, Q.62)

(c) Sketch the general arrangement of a hydropower plant and state the function of its different components. **

(d) Water is flowing through an inclined conical pipe, 100 m long. It has 600 mm diameter at the upper end and 300 mm at the lower end the discharge rate is 50 lit/sec. The pipe has a slope of 1/2:15. Find the pressure at the lower end if the pressure at the upper end is 2.5 bar. (See Unit-III, Page 121, Prob.7)

Or

Water flows through 200 mm diameter pipe. The point A and B are at elevation of 6m and 8m, respectively along the inclined pipe. The pressure at A and B are 50 kPa and 20 kPa, respectively. If the flow

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

rate is 60 lit/s determine
(i) Direction of low
(ii) Head loss between these points **

4. (a) What are the properties of good refrigerant ? **

(b) Prove that $(COP)_R + 1 = (COP)_{H.P}$ **

(c) "Equivalent evaporation from and at 100°C". Explain the meaning of the term and give the reason for its use in the context of boiler performance. (See Unit-IV, Page 175, Q.41)

(d) Obtain an expression for draught produced in mm of water column when the discharge is maximum. (See Unit-IV, Page 181, Q.45)

Or

The pressure volume correlation for a non-flow reversible (quasi-static) process is given by $p = (8 - 4V)$ bar, where V is in m^3. If 150 kJ of work is supplied to the system determine the final pressure and volume of the system. Take initial volume 0.6 m^3. (See Unit-IV, Page 156 Prob.2)

5. (a) What is cut-off ratio ? How does it affect the air standard efficiency of an Otto cycle ? (See Unit-V, Page 226, Q.28)

(b) How is the mean effective pressure for reciprocating engine defined? (See Unit-V, Page 207, Q.9)

(c) Compare diesel engine with petrol engine with reference to maximum pressure, efficiency, power-to-weight ratio, cost and load control. Give explanation. (See Unit-V, Page 256, Q.51)

(d) A gas engine working on Otto cycle operates with the following parameters–Iinlet condition 1 bar pressure 320 K temperature compression ratio 4:1 and pressure ratio 4:1. If the working fluid is air with R = 287 J/kg k and $\gamma = 1.4$. Make calculation for useful workdone, thermal efficiency and mean effective pressure. (See Unit-V, Page 236, Prob.11)

Or

With the help of p-v and t-s diagrams, show that for the same maximum pressure and heat input.

$\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}$ (See Unit-V, Page 229, Q.31)

RGPV

B.E. (First/Second Semester) EXAMINATION, June 2016 BASIC MECHANICAL ENGINEERING (BE–203)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D part has internal choice.

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

(ii) All parts of each question are to be attempted at one place.

(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.

(iv) Except numericals, Derivation, Design and Drawing etc.

(v) Assume missing data suitably, if any.

(vi) Draw neat and clean sketches\diagrams\figures\wherever required.

1. (a) What is cast iron ? State its composition. **(See Unit-I, Page 5, Q.5)**

(b) State various alloy steels with applications. **(See Unit-I, Page 22, Q.31)**

(c) Define hardness. How it can be measured ? **(See Unit-I, Page 26, Q.38)**

(d) Draw an iron-carbon diagram for steel. **(See Unit-I, Page 13, Q.21)**

Or

Explain the following –

(i) Hooke's law (ii) Modulus of elasticity

(iii) Tensile test of steel.

(See Unit-I, Page 32, Q.50)

2. (a) What are dial gauges ? State its applications.

(See Unit-II, Page 70, Q.46)

(b) How will you measure flow ? Name instruments used.

(See Unit-II, Page 55, Q.25)

(c) Briefly describe the concept of measurement errors.

(See Unit-II, Page 43, Q.4)

(d) Draw a neat sketch of lathe machine showing essential components. State functions of three major components.

(See Unit-II, Page 93, Q.85)

Or

Write brief about drilling machine –

(i) Sketch (ii) Types of drilling machines

(iii) Operations performed.

(See Unit-II, Page 104, Q.96)

3. (a) What do you mean by fluid ? Define any three properties of fluid.

(See Unit-III, Page 107, Q.6)

(b) State Bernoulli's equation for incompressible fluids.

(See Unit-III, Page 114, Q.18)

(c) Describe the working principle of fluid coupling with neat sketch.

(See Unit-III, Page 121, Q.25)

(d) Discuss important steps for developing hydro-electric power with neat sketch. **

Or

Discuss the following (any three)

(i) Base load plants

(ii) Peak load plants **

(iii) Pumped storage plants **

(iv) Types of water turbines. **

4. (a) What is refrigeration ? State its unit. **(See Unit-III, Page 128, Q.35)**

(b) State the classification of boiler. **

(c) Compare forced and induced boiler draught. **(See Unit-IV, Page 161, Q.23)**

(d) Describe the working of vapour compression refrigeration system with neat sketch. **(See Unit-IV, Page 187, Q.50)**

Or **

Calculate the following –

(i) The kinetic energy of a body which has a mass of 5 kg and a velocity of 10 m/s. **

(ii) The change in potential energy of a mass of 5 kg when it is raised a height of 3 m.

(iii) The strain energy stored in a spring compressed by 18 mm from its free length if the spring constant is 1.50 MN/m.

5. (a) State the function of steam engine. State its applications.

(See Unit-V, Page 203, Q.1)

(b) State the operation of four stroke petrol engine.

(See Unit-V, Page 248, Q.39)

(c) Compare Otto and Diesel cycles. **(See Unit-V, Page 225, Q.27)**

(d) Explain the following related to steam engine –

(i) Hypothetical indicator diagram

(ii) Actual indicator diagram.

(See Unit-V, Page 210, Q.15)

Or

Calculate the efficiency of the following ideal cycles when undergone by a perfect gas with a γ value of 1.4.

(i) A sterling cycle operating between a hot reservoir at 600 K and a cold reservoir at 300 K.

(ii) An Otto cycle with a compression ratio of 9.

(iii) A Diesel cycle with a compression ratio of 12 and a cut-off ratio of 2.

(See Unit-V, Page 232, Prob.8)

****Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus**

RGPV

B.E. (First/Second Semester)
EXAMINATION, Dec. 2016
BASIC MECHANICAL ENGINEERING
(BE–203)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D part has internal choice.

(ii) All parts of each question are to be attempted at one place.

(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.

(iv) Except numericals, Derivation, Design and Drawing etc.

1. (a) What is cast iron ? **(See Unit-I, Page 5, Q.4)**

(b) What is carbon steel ? **(See Unit-I, Page 10, Q.14)**

(c) Explain the Hooke's law. **(See Unit-I, Page 31, Q.48)**

(d) Explain the various mechanical properties of material. **(See Unit-I, Page 28, Q.44)**

Or

Give a brief classification of engineering materials. **(See Unit-I, Page 3, Q.2)**

2. (a) What is the use of brittle lacquer method ? **(See Unit-II, Page 61, Q.32)**

(b) What is the use of dynanometer ? **(See Unit-II, Page 64, Q.37)**

(c) Classify the temperature measurement instruments. **(See Unit-II, Page 49, Q.13)**

(d) With the help of neat sketch explain the working of micrometer. **(See Unit-II, Page 69, Q.45)**

Or

Give a general classification of milling machines. **

3. (a) Write the Newton's law of viscosity. **(See Unit-III, Page 110, Q.11)**

(b) What do you understand by the term kinetic energy ? **(See Unit-III, Page 112, Q.15)**

(c) Differentiate compressor with a pump. **(See Unit-III, Page 135, Q.44)**

(d) Explain with suitable diagram working of a fluid coupling. **(See Unit-III, Page 121, Q.25)**

Or

A pipe of 200 m has a slope of 1 in 100 and tapers from 1 m diameter at the high end to 0.4 m at the low end. Rate of water flow is 4000 *l*/min. If the pressure at the high end is 50 kpa, find the pressure at the low end. **(See Unit-III, Page 119, Prob.5)**

4. (a) What is latent heat of vaporization ? **(See Unit-IV, Page 188, Q.53)**

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

(b) What is dryness fraction ? **(See Unit-IV, Page 188, Q.52)**

(c) What is draught ? Write various types. **(See Unit-IV, Page 180, Q.42)**

(d) Steam at a pressure of 10 bar and a dryness of 0.9 enters a superheater and leaves at a temperature of 300°C without a drop in pressure. How much heat has been gained by the steam per kg ? Also determine the change in its internal energy. Consider specific heat at constant pressure $c_p = 2.3$ kJ/kg K. **(See Unit-IV, Page 199, Prob.20)**

Or

Discuss the vapour compression refrigeration system with neat sketch. **

5. (a) What is clearance volume ? **(See Unit-V, Page 208, Q.11)**

(b) Define volumetric efficiency of an engine. **(See Unit-V, Page 260, Q.56)**

(c) Name the different parts of a steam engine. **(See Unit-V, Page 204, Q.4)**

(d) Explain the working of four stroke diesel engine with p-v diagram. **(See Unit-V, Page 256, Q.52)**

Or

A double acting steam engine has a single cylinder of diameter 700 mm by 900 mm and develops 450 kW indicated power at 90 r.p.m. pressure at the point of cut off is 12 bar, back pressure is 1.3 bar and diagram factor is 0.76 calculate the expansion ratio. **(See Unit-V, Page 215, Prob.2)**

RGPV

BT-2003 (CBGS)
B.Tech., First Semester
EXAMINATION, Dec. 2017
Choice Based Grading System (CBGS)
BASIC MECHANICAL ENGINEERING

Note : (i) Attempt any five questions

(ii) All questions carry equal marks.

(iii) In case of any doubt or dispute the English version question should be treated as final.

1. (a) Explain the various mechanical properties of material. **(See Unit-I, Page 28, Q.44)**

(b) Draw the stress-strain diagram for ductile and brittle material. **(See Unit-I, Page 34, Q.54)**

2. (a) Discuss the various types of errors in measurement. **(See Unit-II, Page 45, Q.7)**

(b) What is torque ? What are the methods of measuring the torque ? **(See Unit-II, Page 64, Q.36)**

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

3. (a) Explain the different types of pattern allowances.
(See Unit-II, Page 85, Q.72)

(b) Write the various operations that can be performed on the lathe machines.
(See Unit-II, Page 96, Q.87)

4. (a) What is the difference between the dynamic viscosity and kinematic viscosity ? State Newton's law of viscosity.
(See Unit-III, Page 109, 110 Q. 9, Q.11)

(b) Water is flowing through a pipe having diameter 300 mm and 200 mm at the bottom and upper end respectively. The intensity of pressure at the bottom end is 24.525N/cm^2 and the pressure at the upper end is 9.81N/cm^2. Determine the difference in datum head if the rate of flow through pipe is 40 lit./s. (See Unit-III, Page 118, Prob.4)

5. (a) Write and discuss the Kelvin-Planck and Clausius statements of the second law of thermodynamics. (See Unit-IV, Page 143, Prob.13)

(b) Define the thermodynamic system. Differentiate between open system, closed system and an isolated system.
(See Unit-IV, Page 137, Q.2)

6. (a) What is the difference between the boiler mountings and accessories?
(See Unit-IV, Page 170, Q.32)

(b) In a boiler test 1250 kg of coal is consumed in 24 hours. The mass of water evaporated is 13000 kg and the mean effective pressure is 7 bar. The feed water temperature was 40°C, heating value of coal is 30000 kJ/kg. The enthalpy of 1 kg of steam at 7 bar is 2570.7 kJ. Determine –

(i) Equivalent evaporation per kg of coal

(ii) Efficiency of boiler.

(See Unit-IV, Page 178, Prob.12)

7. (a) Explain with suitable p-v diagram the working principle of a steam engine.
(See Unit-V, Page 209, Q.13)

(b) Differentiate between the spark and compression ignition engine.
(See Unit-V, Page 255, Q.50)

8. Write short note on –

(a) Reciprocating pump (See Unit-III, Page 135, Q.46)

(b) Hardness test (See Unit-I, Page 37, Q.57)

(c) Carnot cycle. (See Unit-V, Page 219, Q.22)

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